GOVERNMENT OF BOMBAY.

PUBLIC WORKS DEPARTMENT.

REPORT

ON THE

NIRA CANAL PROJECT,

POONA DISTRICT.

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NI'RA CANAL.

REPORT.

History of the scheme from the commencement.

1. Owing to the frequent failure and general uncertainty of the rainfall, proposals to provide the eastern districts in the Poona Collectorate with water for irrigation were first made in 1863, when surveys were carried out under the direction of Colonel (now Lieutenant-General) Fife, the Superintending Engineer for Irrigation, for a system of small tanks on the tributary streams in the Mutha and Nira valleys. Numerous sites were examined and schemes drawn up, but the system was abandoned because it proved to be financially impossible, and it was shown that, during years of drought when irrigation is most required, the small streams entirely fail.

2. At the suggestion of Colonel Fife, investigations were made with the object of tapping the main rivers by means of canals at high levels, carried along a contour, so as to command the largest possible area of land. These subsequently led to the development of both the Mutha and Nira Canal projects. The great advantages of this system are that the main streams, fed from the ghâts, can always be depended upon for an unfailing supply of water, and in the event of a failure of rain in the eastern districts, an abundant supply is available as a protection against famine. The canals are also capable of commanding a much larger area at a less cost than by means of a series of small tanks.

With this view, the Nira river was examined in 1864. The accompanying index map (Plate No. 1) shows the district referred to; also for comparison, the line of the Mutha Canal in the adjoining valley is indicated. This preliminary survey proved that a canal taken from near Shirwal, would command an extensive area of country near Bárámati, about the centre of the valley. The result was reported as very satisfactory, but it was found necessary to postpone further investigations owing to all the establishment being required for the Mutha scheme.

3. In 1868, a Committee, consisting of the Survey and Settlement Commissioner, the Collector and the Executive Engineer for Irrigation, was appointed by Government to consider the survey operations to be undertaken for irrigational works. The Committee's report brought prominently to notice the importance of providing a work for irrigation in the Nira Valley, specially mentioning the Indápur Táluka, which lies between the Bhima and Nira rivers, as most urgently requiring protection.

Accordingly the survey of the Nira scheme was resumed in 1868 by Lieutenant Buckle, R. E., Executive Engineer for Irrigation, who proceeded with the work till the close of the year, when he took charge of the Mutha Canal works, and Mr. J. E. Whiting was appointed on special duty to continue the survey under the orders of Colonel Fife, Superintending Engineer for Irrigation.

4. Mr. Whiting submitted his report, with complete plans and estimates, for the Nira Canal Project in 1871, to the Superintending Engineer for Irrigation. It was held in abeyance for some time pending the discussion with the revenue authorities regarding the probable revenue to be derived from the work, also owing to some uncertainty as to the financial success of irrigation works in the Deccan. It was not till 1877 that the complete scheme, with an exhaustive report by the Superintending Engineer for Irrigation, was forwarded to Government for sanction.

In 1876-77 the earthworks of a section of the canal were commenced for the employment of people suffering from the effects of famine. After the cessation of the famine pressure, the masonry head-works were proceeded with, but were suspended in October 1878, pending the sanction of the Secretary of State. From March to September 1878, and again from March 1879 to March 1880, the works were re-opened for the employment of the people suffering from the distress caused by high prices of food and failure of crops from the ravages of rats.

In February 1881 the works were again continued, sanction having been accorded to the completion of the head-works and first 35 miles of the canal.

The year 1881-82 marks a very important stage in the history of the scheme, as in May 1881 the sanction of the Secretary of State was received to the complete scheme being undertaken from the grant for Protective Works. From this date the works were proceeded with without any further serious interruption.

Description of the scheme.

5. The scheme sanctioned in 1881 was that drawn up by Mr. Whiting in 1871, and submitted by the Bombay Government in 1877. It provided for a reservoir at Bhátghar on the Yelwandi river, a tributary of the Nira, and a canal on the left bank of the river with head-works at Vir, on the Nira, 19¼ miles below the reservoir site, 129 miles long, discharging 945 cubic feet per second at the head.

The estimated cost of this project was as follows :—

		Rs.
Bhátghar reservoir		16,62,387
Canal Head works		4,20,288
Main Canal and Distributaries		25,58,858
	Works ...	46,41,533
	Establishment ...	7,44,712
	Tools ...	89,310
	Total Direct Charges ...	54,75,555

6. In reviewing the project the Superintending Engineer for Irrigation (Colonel Merriman, R. E.), after full consideration of the probable financial success of the work, proposed that it should be carried out in three stages.

The first, comprising the canal with carrying capacity of 455 cubic feet per second.

The second, the same canal with the storage reservoir.

The third, the complete scheme, with the canal enlarged.

The Superintending Engineer recommended that the smaller scheme *i.e.*, 1st and 2nd stages, should be undertaken and completed first, and that the 3rd stage be delayed until the development of irrigation under the smaller scheme showed the necessity for enlarging the canal to the maximum discharging capacity of 945 cubic feet per second.

7. These recommendations were adopted, and the estimate eventually sanctioned by the Secretary of State in 1881 was for the first two stages, and amounted to Rs. 39,77,355, thus :—

		Rs.
Works { 1st stage		16,64,873
Works { 2nd „		16,74,387
		33,39,260
Establishment		5,74,232
Tools		63,863
	Total Direct Charges ...	39,77,355

8. As the construction of the works proceeded, many alterations in the design and improvements in the canal alignment were found necessary, and resulted in the revision of the estimates. The total amount for "Works" was less than the original by Rs. 81,817; the increased provision, however, for Establishment and Tools brought the total of Direct Charges to the same as before, viz., Rs. 39,77,355. The most important alteration in this estimate was the reduction in the provision for the Bhátghar Dam. The original estimates for this work amounted to Rs. 11,42,473, and the revised estimate of 1883-84 provided Rs. 7,98,342 or a saving of Rs. 3,44,131. This was due to alterations in the alignment and design by a reduction in the section of the dam, by the substitution of concrete for masonry in a large portion of the hearting of the dam, and by a general reduction of rates. This revised estimate was sanctioned by the Government of India in December 1884.

9. Subsequently as the works advanced, further additions and improvements were found necessary. These, together with extra work in foundation, a revision in the details of the design for Bhátghar Dam and a general increase in the cost of labour throughout the district, showed that an excess would be caused on the sanctioned estimate. A complete revised recapitulation of the estimate was therefore prepared and submitted to the Government of India in June 1887. The amount of this estimate was Rs. 48,85,328 for Direct Charges thus :—

	Rs.
Works	38,87,983
Establishment	8,79,731
Tools	1,17,614
Total Direct Charges ...	48,85,328

or Rs. 9,07,973 in excess of the original estimate.

Sanction to this estimate was accorded in Government Resolution No. 1652 of 25th September 1889.

10. The alteration in design for storing water at Bhátghar between weir crest and highest flood level, together with the rate for concrete and masonry having been under-estimated, again caused an excess on the last sanctioned estimate and a further revision has been found necessary. The figures of the final revised estimates are as follows :—

	Rs.
Works	43,54,655
Establishment	12,46,486
Tools	1,41,465
Total Direct Charges ...	57,42,606

or Rs. 17,65,251 in excess of the original estimate.

Description of the works as carried out.

11. The Nira Canal Project as actually carried out differs only in details from that submitted to Government for sanction in 1877. It may be described under two heads.

(1). The main canal with head works at Vir.

(2). The storage reservoir at Bhátghar.

Canal Head works.

12. The head works are situated on the Nira river about 10 miles east of the main Poona-Dhárwár Road and close to the village of Vir, in the Purandhur Táluka. They consist of a weir built across the river at right angles to its direction of flow, and continued through the left or north bank, in a curve to the east so as to cross a large water-course called the Vir nalla at right angles, this end portion of the weir being parallel with the main river.

Two subsidiary weirs are constructed below the main weir. One across the Vir nalla is 303 feet long, 50 feet from, and with its crest 14·5 feet below that of the main weir. The second is built across the Nira river, at a distance of 1040 feet from the main weir. Its length is 615 feet and its crest at a level, 24·5 feet lower than that of the main weir, against which therefore a depth of 18 feet of water is headed up. The general plan and detail of the head-works are shewn on Plates Nos. 2 and 3.

The site of the main weir is that selected originally by Mr. Whiting. Before beginning the work, a second site, for a shorter weir, was proposed lower down the river than the first. Many engineers who have visited the head-works, since they were built, have inquired why the long weir was built instead of a shorter one on a site apparently favourable lower down the river. Estimates were prepared for weirs on both sites, that on the lower being considerably the cheaper. It was however rejected in favour of the long weir on the upper site, the chief points in favour of which were (1) that the flood level being less interfered with in the longer weir, the cascade will be less and the disturbance will extend a shorter distance up the river, thereby interfering less with the existing state of

things, notably with the Shirwal bridge on the main Poona-Dhárwár Road* and the lands on the banks of the river; (2) that the head sluices are more favourably placed as regards silting and safety; (3) and that the foundations, being at a higher level, there would be less difficulty in laying them.

Description of the main weir.

13. The weir was therefore built on this site. It has a clear length of overfall of 2,273 feet, the crest being 42 feet above the original bed of the river. The breadth at the crest level is 9 feet and at river bed, 26 feet. The batter of the up-stream face is 1 in 40 and of the down-stream face 1 in 3 for a height of 29 feet from the top and 1 in 2 below to the foundations. The south end of the weir abuts on the bare rock which forms the right bank of the Nira river, the east end, on the left bank of the Vir nalla and joining the cross wall forming the head regulator of the canal. The base of the weir up to 26 feet from the crest is constructed of heavy rubble masonry, the rest being of concrete between two faces of rubble 2½ feet thick on the down-stream and 2 feet on the up-stream, the crest being curved at the up-stream edge, and covered with rubble paving, 9 inches thick. Masonry was used in the river crossings, as it was considerd it would offer, when fresh, more resistance to injury than concrete, in case of sudden floods which might occur during construction.

14. Many difficulties were met with in laying the foundations across the main river and building the portion of the weir between the two rivers where it was in cutting 53 feet in depth. During heavy floods the work in this portion was always covered with earth and silt, which had to be cleared away and interfered greatly with the progress of the work. A strong spring was met with in the founds in the river, but was eventually built over by means of a small culvert, the portion of the dam on each side being built out from the general line of the toe of the dam, by means of footings, to give additional strength at this place. The chief difficulty was encountered in a portion of the founds near the left bank of the main river, where a dyke of soft stuff with large boulders was met with. This had all to be excavated for a depth of from 5 to 12 feet, and length of 96 feet, the springs of water being kept down by means of a centrifugal pump. The weir was successfully founded throughout on solid rock, and the portion of the excavation at the down-stream toe was filled in up to surface of rock with concrete, to prevent any wearing away of the rock close to the foundation. It will be seen by reference to Plate No. 2 that the only connection between the canal sluices and the main river is by the channel at the up-stream side of the weir, where it is in deep excavation between the two rivers. Several deep cuts about 6 feet wide were made through the high ground both above and below the weir, in the hopes that more would gradually be carried away during succeeding floods. The material is a hard, compact, gritty red earth, interspersed with nodules of kunker. The surface, when wet, resists the action of water, even if falling from a considerable height, like solid rock. When allowed to dry, it disintegrates, and only a thin layer of it is washed away every year. It has therefore been found necessary to cut away a great deal of these high banks above the weir to improve the approach, and below, to prevent the weir at this place being drowned in heavy floods. Some of the cuts however near the left bank of the main river, where bands of sand occurred under the red earth, were very effectual in carrying away large masses, and the approach to the weir will improve every year. Two sluice openings have been left in this curved portion of the weir, to carry off the earth, that falls in during floods, and to keep the channel clear. They are each 8′ × 4′ with sills at 9½ feet below the crest of the weir, and are closed after the monsoon by means of needles. In order to prevent an accumulation of silt in front of the canal regulator, two scouring sluices were built in the main weir at the extreme east end, and joining the canal head regulator. Originally these were 3 feet wide by 2 feet high with their sills 9·4 feet below the crest of the weir and 1 foot below the canal sluices. It was soon found that these were not sufficient to carry off the silt, a large quantity of which was deposited close to the canal sluices after every heavy flood in the Vir nalla. They were therefore replaced by two sluice gates each 3 feet wide × 4½ feet high with

* Raised 8 feet in 1887.

sills, 12 feet below weir crest and $3\frac{1}{2}$ feet lower than the canal sluices. They have proved very effective in keeping down the silt, but experience shows that four such sluices at a level 2 feet lower still would have been better.

In addition to these a sluice opening has been made in the centre of the weir across the Vir nála, and is closed by a falling gate designed by Mr. Whiting and erected as an experiment. This sluice is $8' \times 4'$ with its sill at $11\frac{3}{4}$ feet below the weir crest, and has proved very effective as a scouring sluice.

The construction of the main weir was commenced in 1878 and completed up to within 3 feet of full height, in 1885. It was left at this height until the subsidiary weir across the Nira was built, *i. e.*, in 1886-87, when it was completed to full height across both rivers, the intermediate portion being left at levels varying from 1′ to $3\frac{1}{2}$′ below full height, in order to draw the current of water and direct its action on the earth banks, which it was necessary to remove. The weir has since been gradually raised, but a portion about 400 feet in length will be allowed to remain for a few seasons 15″ below full designed level, so as to facilitate scour, where it is still needed.

The subsidiary weir across the main river.

15. In the original design for the head-works it was intended to locate the subsidiary weir across the river about 2,800 feet below the main weir. Subsequently it was proposed to build it above the junction of the Vir nála with main river, so as to prevent injury to the canal which is in deep cutting and very close to the bank of the river for some distance. In this position the north end of the subsidiary weir would abut on the left bank of the river, where costly protective works would be required to protect this bank from being washed away; for this and other reasons, the site was abandoned in favour of that on which the weir has been built, at the junction of the two rivers, and 1,040 feet below the main weir. The total length of the subsidiary weir is 615 feet. It is 9 feet wide at top and 20 feet at river bed level.

Both the up-stream and down-stream faces have the uniform batter of 1 in 4. It is built entirely of concrete between two faces of rubble masonry. The centre portion of the crest is horizontal for a distance of 280 feet, the two end portions being raised to the flanks on each side in slopes of 1 in 30 with the object of obtaining a greater depth of discharge and so secure a higher back-water against the main weir. When the monsoon floods have subsided, wrought-iron standards carrying a wire rope as a railing are fixed on the up and down stream sides of the crest, muram is filled in between two low parapets and the top of the weir is used as a road leading to the main Shirval-Phaltan Road. The work was commenced in 1885 and finished in 1887.

Discharging capacity of the weirs.

16. The highest known flood, (in 1854), was calculated from information supplied by the inhabitants to have been discharged at the rate 1,58,000 cubic feet per second. The aggregate catchment area is 700 square miles, of which 65 square miles belong to the Vir nála, and this flood corresponds approximately to a run off of half inch per hour per square mile for the Vir nála and one-third inch for the Nira river. The main weir, it is calculated, would discharge this maximum flood, with the uniform head of 7 feet over the entire length, and the subsidiary weir would discharge the same flood with a head of 20 feet.

The peculiarity of the maximum flood mentioned above was that both the Nira river and the Vir nála were in highest flood at the same time, an occurrence that from experience very rarely happens. The highest floods occur generally in the month of July for the Nira, and in the month of May or October for the Vir nála. The highest flood in the Nira accurately gauged since the construction of the works, occurred on the 3rd of July 1888, when the discharge was 92,697 cubic feet per second. The height over the finished crest was 7·6 feet in the Nira, and only 2 feet over the same level in Vir nála portion. This was due chiefly to the fact that the portion of the weir between the two rivers was low and allowed much of the water to pass off before reaching the east end of the weir; it was however also due to the passage between the two rivers being too contracted to allow the east end to draw properly. The bank above the weir has been consequently cut away and the channel widened; whether

the entire length of the weir will be operative in the case of a heavy flood in the Nira alone cannot be ascertained until the remaining 400 feet is built up to finished crest level. The highest flood gauged in the Vir nála since the works were completed occurred on 31st May 1889, when the water rose to 3·10 feet above crest, the height in the main river over the same crest level was nil. The flood of the 3rd July 1888 rose to a height of 14·20 feet above the crest of the subsidiary weir, heading up the water against the main weir to a depth of 32·20 feet above river bed. It is, however, very improbable that the maximum flood of 158,000 cubic feet per second will occur, except when both rivers are discharging full, and therefore the whole length of the weir would be in operation. It will be seen from the diagram showing the stability of the main weir on Plate No. X that the maximum flood is shown to be headed up to 11 feet above crest. This represents the most unfavourable conditions possible, namely, a maximum flood in the Nira river alone, before the high banks above the curved portion have been scoured away to give free passage to the east end portion of the weir. Under these conditions the vertical pressure at the outer toe is 68·8 lbs. per square inch, and the combined resultant falls within the middle third of the section at the base. The average weight of materials is taken in this calculation at 160 lbs. per cubic foot.

Quantity and cost.

17. The quantity of work executed in the main weir was as follows:—

Rubble masonry 511,284 cubic feet, costing Rs. 1,10,122 or at the rate of Rs. 21¾ per 100 cubic feet.

Concrete 741,773 cubic feet, costing Rs. 95,222 or at the rate of Rs. 12¾ per 100 cubic feet.

Main Canal.

The Head Regulator.

18. The Head Regulator of the Nira Left Bank canal consists of a masonry wall, built at the extreme east end of the main weir and at right angles to it. In this wall are built 7 sluices, closed by cast-iron gates, each 4′ × 4′, which can be raised or lowered by simple screw and nut gearing, worked by means of a W. I. spanner. The sills of these sluices are 8·5 feet below the crest of the weir and 34 feet above the bed of the Nira river. The top of the wall, from which the canal and also the two main scouring sluices are worked, is 13 feet above the crest of the weir, or 6 feet above highest flood level.

Canal alignment.

19. The canal, starting from the Head Regulator, in cutting a little over 30 feet in depth, follows the contour of the country, except at nála crossings, and where it was found more economical to cut through some of the cross ridges, until it reaches the water shed between the Nira and Bhima valleys, west of the town of Indápur. The total length of the canal up to this point is 101 miles, or 2 miles less than the line estimated for originally. The canal is designed to carry 455 cubic feet per second at the head, with a depth of 7·50 feet and 91 cubic feet per second, where it tails into the end distributary with a depth of 6 feet, the discharge being regulated according to the estimated draw off by means of the distributaries. The cross section of the canal is designed according to the nature of the material met with. In soil the slopes are 1½ to 1, in murum 1 to 1, in soft rock ½ to 1, and in hard rock they are vertical; the bottom width is fixed according to the required discharge, the maximum being 23 feet and the minimum 6 feet in the rock cutting in the 98th mile. The inclination of the bed varies from 5 to 6 inches per mile in soil, up to a maximum of 8 feet per mile in hard rock, the velocity varying from 1·5 feet per second to 5 feet per second. The total fall, between the head and the extreme end of the canal, is 96·15 feet, or a mean inclination of 0·96 feet per mile.

The canal is in double bank throughout, with a few unimportant exceptions, where it skirts steep rocky spurs, the run off from which is very small. Even in these cases low banks are generally provided from the canal excavation, and the drainage led to the most convenient inlet. The lower bank is made up to a height of 4 feet and the upper bank 2 feet above the canal final full supply; where the banks approach large cross drainage works an additional height of 1 foot is allowed. The index map gives a fair idea of the nature of the country through

which the canal passes and it will be seen that great skill and judgment was required to locate the line so as to obtain the best crossings of the numerous water-courses with the intermediate alignment as short and economical as possible. The difficulties in settling the final line were increased by the fact that in order to provide work for famine labour, the excavation and embankment were first commenced hurriedly at different points, *viz.*, the 1st, the 44th to 48th, the 66th, the 89th mile. These being fixed points as regards bed level, the intermediate lengths had to be finally aligned with these limiting conditions. The portion that presented probably the greatest difficulties in alignment and construction was the first five miles, where the canal keeps close to the bank of the river and has to cross many deep and precipitous ravines in addition to 4 or 5 large nálas with extensive catchments.

The first 1½ miles, in particular, is a series of high embankments and deep cuttings through a hard yellow earth with bands and nodules of kunker. This was the only material available for the banks at this place and has proved to be most unsuitable and unreliable, as it absorbs water and heavy banks are liable to slip frequently.

The other points of interest to be noted are the deep rock cuttings through ridges thus :—

Name of Cut.	Canal mile.	Greatest depth of cutting.	Length of the Cut.
Koralla	30	35·57	4,725
Málegaon	38	32·07	3,460
Nimbgaon	91	35·30	2,707
Warapuri	96	30·57	1,719

In all these cases it was found more economical to take the canal across the ridges than to follow the contour. The other advantages are a saving of head and reduced length of main canal to maintain. The drawback is the length of distributaries required to be taken round spurs through hard cuttings. The reduction in the length of the canal by these short cuts amounted to not less than 20 miles.

Canal bank.

20. It has been found from the experience of five years that the form of bank that is in every way the most reliable and the easiest to maintain in good order, is one constructed with a centre core of red *mān* earth, or brown soil, 3 feet wide, the rest of the section being made up with murum (disintegrated surface trap rock). After a year or two the surface gets covered with grass and the bank keeps its form better than if constructed with any other material. The banks that have given the greatest trouble are those made of yellow soil, intermixed with kunker and known as kurral soil. The banks over 20′ in height close to two aqueducts in the 66 and 67 miles, also lower banks in other places, have failed, owing to this yellow soil getting saturated with water and turning into mud at the base of the banks. The weight of the material above forces the soft material out and the bank thus slips away. Two methods have been tried to make these banks safe. Trenches were dug at the outside toe, parallel with the canal, and also cross trenches into the bank; these were filled with small rubble, the outer wall being carefully built up with dry stone. The effect is to drain away all leakage, leaving the bank comparatively dry. This has been only partially successful, because the trenches get gradually filled up during heavy rains. The method, that after a trial of nearly two years has proved quite successful, is to dig a trench two feet wide on the inside of the bank parallel to the canal, from full supply level to the natural ground, or deeper, according to the nature of the material. This trench is filled with good clay puddle, made in the usual way, the top 1½ feet, near the surface, being made up with earth and murum. In the case of a breach all the wet material is carefully removed, fresh dry soil being used for the new bank, which is constructed in layers, and worked up at the same time as the puddle trench. The same difficulty has been met with, as in

all other Deccan works, where the canal is in excavation in black cotton soil. This soil, in the dry weather, shrinks, and deep cracks are formed, into which the canal water runs, and sometimes undermines and carries away the banks. The canal has to be watched and the cracks filled in with murum and soil mixed.

The quantities of earthwork executed are as follows:—

	Cubic feet.	Cost.	Rate.
		Rs.	Rs. a. p.
Excavation in soil	25,607,812	85,098	0 5 3
Do. in soft murum	10,711,447	45,984	0 6 10
Do. in hard murum	12,721,410	79,389	0 9 11
Do. in soft rock	12,913,913	1,89,246	1 7 5
Do. in hard rock	8,891,171	2,33,835	2 10 1
Embankment	104,439,429	5,26,079	0 8 0
Sundries	.....	7,285	.....
Total ...	.....	11,66,915	

Drainage works.

21. The canal being in double bank practically throughout, all the drainage from above has to be passed either over or under the canal. This has been done by means of 18 aqueducts, 90 culverts and 9 super-passages or a total number of 117 drainage works. This is at the rate of 1·16 per mile of canal. In addition to these, escapes are provided at suitable places all along the canal. All details regarding the masonry works, as they occur on the canal from the head-works, are given in Appendix No. IV. In lining out the canal, nála crossings had to be fixed so as to secure good foundations, sufficient headway, and wherever possible, the site was chosen below the junction of two or more nálas, so that one work should provide for the largest possible drainage area. Where this was not feasible small water-courses were banked across and their flood waters led by means of "upper cuts" to the nearest drainage work. In all doubtful cases, the class of drainage work to be adopted, whether aqueduct, culvert or super-passage, was determined by surveys and comparative estimates. The amount of water-way to be provided was fixed according to the run off from the catchments. The areas of these were taken from the topographical maps, published on a scale of one mile to the inch. The district through which the canal passes being subject to storms of great intensity a high run off varying with the area of the catchment had to be provided for. It may be noted here that on one occasion a fall of $2\frac{3}{4}$ inches in three-fourth of an hour was gauged by one of the Assistant Engineers on the canal. Thus the maximum run off for areas up to half square mile and under was taken at 3″: for 1 to 5 square miles 2″: for larger areas the run off varied from 1″ to $\frac{1}{2}$″, and in the case of the Kara river, with a catchment of over 400 square miles $\frac{1}{3}$″ was allowed. No serious difficulties were encountered in obtaining sound rock foundations for all the larger works. In the case of some of the culverts where hard rock was not available except at great depths, soft rock, hard murum or even hard *mân* earth which overlies the trap rock, were passed, care being taken to found at a depth, secure from all possible danger from scour.

The sanctioned project provides for a discharge in the canal of 455 cubic feet per second at the head, *i. e.*, according to the 1st and 2nd stages. The 3rd stage contemplates enlarging the canal to carry on greater discharge, fixed in the original design at 945 cubic feet a second, but subsequently reduced to 760 cubic feet a second. All the masonry works have therefore been built to carry the ultimate maximum discharge.

Aqueducts.

22. The typical design of aqueducts is shown on Plate No. V. With one or two exceptions they were designed with spans of 30 feet, so that the same set of timber centres could be used for all. Teakwood centres for three arches were made, and when all the aqueducts were completed, they were cut up and used for the roof and wood-work

in the canal bungalows. The chief feature in the design is the use of dry stone work in the wing walls instead of rubble masonry. Short curved rubble masonry wings are built out from the aqueduct, ending in curved profile walls, from which the incurvated dry stone wings are built, the top of the walls following the slope of the bank and terminating in each case in one point at or below ground level, according to the nature of the ground. In every case the dry stone work is based on a bed of concrete founded on rock, and taken to a height slightly above ground level, thus forming a firm and secure toe to the dry stone work. Some doubt existed at first, as to this class of work being sufficiently stable to resist the earth pressure, in the case of high embankment. In two cases, the dry stone wing walls showed signs of failure and were removed and replaced by rubble masonry. These were two of the first that were built and the failure was due to the fact that they had not been properly constructed. After a trial of 5 years the walls that were correctly built, have stood well and although the canal has never carried the full discharge, and therefore the maximum test has not yet been applied, there is every reason to believe that they will prove amply strong to bear the test. The only advantage that this class of work has over rubble masonry is that it is somewhat cheaper, notwithstanding the fact that the section for dry stone is considerably greater than that required for masonry. Dry stone wings, cost on the average Rs. 10 against Rs. 18 per 100 cubic feet for masonry. Another important feature in the design for the aqueducts is that a large saving in cost was effected by making the masonry channel of smaller section than the main canal, by increasing the bed fall. This is done as much as possible without sacrificing too much fall and without causing a heading up in the canal. A fall of 4″ in 40 or 50 feet is given, sufficient to generate the required velocity in the approach, which is narrowed to form an adjutage to the aqueduct. It was calculated that the acceleration along this steep incline together with the original velocity of approach would give the required speed before the water entered the aqueduct, the inclination given along the aqueduct being sufficient to maintain this velocity. On the down-stream side, the canal is gradually widened out, and the regular bed fall resumed. The two most important aqueducts as regards size are No. 10 in the 26th mile, having 8 spans each 30 feet, and No. 14 in the 46th mile over the Kara river, having 13 spans each of 30′. The Kara aqueduct is the work of greatest interest and importance in the Níra Project next to the storage reservoir and canal head-works. The catchment area is 440 square miles; the fall of the river is 9 feet per mile, and provision has been made at the aqueduct for a run off of $\frac{1}{3}$rd of an inch per hour per square mile. The maximum height of piers is 17 feet from river bed to springing, and the clear length between abutments is 436 feet. The total waterway up to springing is 5,920 square feet.

Mr. Whiting, in submitting the design for this work, remarked as follows :—

"The cost of the aqueduct varies directly as the river discharge and the canal full supply. The product of these is therefore a measure for comparison. This product divided by the total cost, including banks, makes the *hydraulic efficiency* 1,000 cubic feet per second for less than one rupee. Probably the Kara is one of the largest torrents yet crossed by a canal line and may be taken as an illustration of the facilities which the Nira Valley affords for constructing an irrigation work."

This aqueduct is shown with details in Plates Nos. V and VA.

Culverts.

23. The two principal types are shown on Plates Nos. 7 and 8. The former was used when the available headway was limited. The centre portion of this arch is of rubble, of minimum thickness, and the portions under the banks are of concrete thicker than the rubble arching. The area of the opening is increased uniformly from the centre portion of the culvert, towards both up and down stream faces, giving a trumpet shaped approach and delivery which adds considerably to the discharging power. In many cases it was found impossible to cross nálas, so as to secure sufficient headway. A plan was, therefore, adopted, that has proved generally successful. The bed of such a water-course was excavated so as to give the required headway, a steep incline being given above the culvert, and the new bed taken at an inclination of 1 in 500 or more, and the excavation continued down stream, till the original natural nála bed was reached. These

cuts have acted very efficiently, where the catchments were hard and rocky and the natural nála beds steep. With blacksoil catchments, however, some of the excavations have been silted up and will eventually have to be cleared; where ample headway was available, the arch was built in the form of an ellipse with the major axis vertical and the springing at ground-level (Plate No. 8). The whole culvert was built of concrete, with the exception of the faces of the arch and the small parapets and wing walls in which it was found cheaper to use rubble masonry. In building the arch the concrete was laid in radial 6″ courses, until the inclination became too great to secure proper ramming. The courses were then laid circumferentially. Solid centring of stone, murum and earth was used for these arches and for all works having a less span than 30 feet. The largest concrete arch has a span of 26 feet, with minimum thickness at crown of 18″. The cost of the concrete arching varied from Rs. 14 to Rs. 16 per 100 cubic feet.

Super-passages.

24. These were designed for the crossing of several large nálas, with low banks, and sandy beds having comparatively little fall, for which the cost of aqueducts or culverts would have been excessive. Plate No. 4 shows the design adopted. They have proved to be complicated and difficult to build, and act much more than anticipated as silt traps. They are inconceivably ugly in appearance, obstructive in their action, as regards canal discharge, and the only blot among the numerous well designed handsome masonry works on the canal. The sole reason for their existence is economy in original cost.

25. *Twenty-four overbridges* have been constructed to provide for the principal roads; also several foot-bridges. In addition to these, road crossings are made under most of the aqueducts and culverts.

Distributaries.

26. The land commanded by the canal is bounded by the Níra river on the south and the canal on the north, the gross area being 274,447 acres or 429 square miles. Water for irrigation is supplied to this area by means of 65 distributaries (including pipe outlets) the total combined length of which amounts to 152 miles. The area commanded by each distributary has been ascertained by actual survey. The unculturable and waste land was obtained from the village registers, and the land too high to be commanded by the distributaries surveyed. The total of this unirrigable land was deducted from the gross area, the result being the net irrigable area commanded. For the whole canal out of a gross command of 274,447 acres, the net irrigable area is 227,670 acres or 356 square miles. The first distributary is taken from the canal in the 9th mile and commands 60 acres, the largest is No. 59 in the 96th mile with a gross command of 57,242 acres. Detailed information regarding all the distributaries is given in Appendix No. V. The canal outlets to distributaries are of two patterns. For small channels, C. I. pipes are laid under the bank and fitted on the outside of bank with sluice valve, enclosed in small masonry cisterns, which are closed by wooden shutters kept under lock and key. These pipe outlets vary in size from 6″ to a maximum of 12″ diameter. For the larger distributaries a masonry head wall is built, with an opening of the required size at canal bed level, communicating with the distributary by means of a culvert under the bank. The opening is closed by a cast-iron gate, working in a C. I. frame bolted to the masonry face, and is raised or lowered by a screw rod, with the thrust-box fixed at the top of the head-wall, the nut of gun metal being worked by a W. I. spanner. When the gate is closed the top of the screw rod is flush with the top of the bolt and the height to which the gate is opened can be readily measured by the length of screw above the top of the nut. This form of outlet is very efficient, simple in construction, easily worked and economical. Plate No. 9 shows very clearly the system of distributaries, and it will be seen that as a general rule a distributary is provided to command the land between every two large nálas. In fixing the carrying capacity of the channels the average duty of water was assumed at 100 acres per cubic foot per second. It was also assumed that not more than 50 per cent. of the total net irrigable area commanded would be under irrigation in any one season. The discharge therefore at the head of each channel is fixed on the basis of one cubic foot per second for every 200 acres of command. It will be seen from Appendix No. V that in many

cases the calculated full discharge is less than that arrived at by the above rule. The channels are generally in excavation to a depth nearly equal to the depth of full supply, the excavated material being used for banks on each side of the channel. It was therefore estimated that the full required discharge could be obtained by slightly increasing the depth of water in the channel and in the case of the area of irrigation increasing beyond the proportion estimated for, the discharge could be increased without difficulty according to the demand by raising the banks. This has already been done in some of the smaller distributaries, but experience shews that for commands up to 3,000 acres, where the soil is good, and the land suitably situated for irrigation it would be better to design the channels on a basis of 150 acres to the cubic foot per second. Beyond this limit 200 acres to the cubic foot is ample. It may be noted that this rule applies strictly to Deccan irrigation. A rice district for instance would be treated on a different basis.

27. The usual alignment of the distributaries is as follows. The position of the Head Regulator having been fixed, the channel is taken in contour falling 3 feet a mile, until the ridge between the two valleys to be commanded is reached. The channel then follows the ridge line, except at those places where land rises, and is too high to be commanded, and where the channel has to be taken round it in contour. These high lands are shown coloured red, in Plate No. 9. The length of the distributaries and their branches are fixed, so that the field channels constructed by the cultivators shall not exceed about 3 miles in length. As the fall of the country from the canal towards the river is generally much greater than that suitable for a channel, the inclination of the bed, designed according to the material passed through, is obtained by introducing a series of masonry vertical drops. In small channels where a hard bed was met with, such as soft rock or hard murum, the drop from one inclination to the next was obtained by a "rapid" 40 or 50 feet in length, no masonry work being then needed. Several designs for the vertical drops were tried but the best and simplest consists of a plain masonry wall built across the channel, with a V shaped notch, designed according to the full supply of the channel, and with its sill at the level of the upper bed of channel. Wing walls are provided for the protection of the banks on each side, and the water on passing through the notch falls on a low concrete cistern forming a cushion of water. The height of the drops varies from 2 feet to a maximum of 5 feet. When the distributary is in contour, the drainage is kept out of the channel by an upper bank and the flood water taken either over or under the canal by aqueducts, culverts or super-passages. Great economy was effected by using concrete in all the masonry works and dry stone for the wing walls of the vertical drops. Some of the latter were built entirely of dry stone, on the small distributaries, but have not proved very successful and are gradually being replaced by rubble masonry and concrete. The greatest difficulty, experienced in the working of the distributaries is when they are in excavation in black soil. The sides of the excavation erode rapidly, and the soil by shrinking and cracking causes frequent breaches. Pitching has to be provided, to keep the shape of the channel and the banks have to be watched and repaired constantly. All the distributaries up to and including No. 59 in the 96th mile have been constructed. The two end distributaries have been surveyed but will not be built until the irrigation from the others has developed to some extent. The total cost of all distributaries in operation has been Rs. 1,86,650 for net irrigable command of 1,83,862 acres, or at the rate of 1·01 per acre.

Irrigating capacity of the work.

28. As the Nira Canal has been constructed with the principal object of protecting the district in the event of a failure of the rainfall, the measure of the irrigating capacity of the work must be estimated under special conditions. In the event of a famine nearly the whole of the available supply, in either a kharif or a rábi season, would be required for the irrigation of the ordinary dry-crop, such as bájri or jowári. From actual observation on a number of the distributaries, it has been found that the duty of water for these crops to a base of four months is fully 200 acres to the cubic foot per second; as however there would always be a certain area of perennial and garden irrigation to provide for, a fair duty to assume is 160 acres to cubic foot. The full discharging capacity

of the canal at the head is 455 cubic feet per second. From careful experiments with the canal it has been found that the loss by evaporation and absorption amounts to 1 cubic foot per second per mile. The total available supply would be only 354 cubic feet per second and the irrigating capacity of the canal therefore under these conditions would be $354 \times 160 = 56,640$ acres, or 24·9 per cent. of the total net irrigable area under command. The canal, if extended to the 3rd stage, would discharge 760 cubic feet per second, and its irrigating capacity would be 105,440 acres, or 46 per cent. of the command. The results obtained for the loss by leakage in the canal, correspond very closely with those obtained on the Mutha Canal, where the loss was found to be between 0·8 and 0·9 cubic feet per second per mile. The Nira Canal, however, at the time of the experiment, had only been in operation for a short time. Several large leaks have since been stopped, and the chief percolation which occurs in the murum and surface rock cuttings will, it is expected, diminish to a certain extent, in time as the cracks and crevices become puddled with silt. It must be noted, that leakage water from the canal is not all wasted, for much of it is picked up in the nálás and used for irrigation, and water-rates charged for it. The whole country below the canal derives a benefit from percolation, the value of which it is impossible to estimate. Direct evidence of this is given by the records shewing levels of water in wells before and after the construction of the canal, also by nálás that were formerly dried up in the cold weather now having a perennial flow.

The Storage Reservoir.

28A. The Nira River during the south-west monsoon discharges very much in excess of the requirements of the canal, but after October the supply rapidly diminishes, and from January to June, it is practically nil. In order therefore to secure an unfailing supply in the canal, throughout the year, a storage reservoir has been constructed at Bhátghar near the town of Bhore, and on the Yelwandi River, a ghat—fed tributary of the Nira.

Selection of site.

29. The back-water from the main weir at Vir extends to a short distance west of the Shirwal bridge on the Poona—Dhárwár Road. The main river therefore and its tributaries, above this point were examined with a view to obtaining the best possible site for a dam. The catchment being situated in the Western Ghats, having an average rainfall of over 250 inches, the conditions affecting the selection of the site were (1) foundations for a masonry dam, (2) accommodation for a large waste weir, (3) extensive reservoir capacity, with a catchment area not too large, (4) supply of materials and their transport to the work. These conditions were fulfilled best by the site finally selected on which the dam has been built. It is on the Yelwandi River, just above its junction with the Nira, and about 19 miles west of the canal head works, with a catchment area of 128 square miles. The general plan of the dam and waste weirs is shown on Plate No. 12.

General Description.

30. The dam of masonry and concrete is 3,020 feet long with a maximum height of 127 feet above lowest foundation and 103 above the bed of the river, the width at full supply level being $12\frac{1}{2}$ feet and the maximum width at base 76 feet. Two waste weirs are provided one at the south and one at the north end of the dam. A roadway, with clear width of 11 feet, is constructed on the top of the dam and carried over the waste weirs by means of piers and arches. The combined length of the dam and weirs is 4,067 feet, the clear length of water way on the two weirs being 810 feet, calculated to discharge the maximum flood with a head of 8 feet.

31. Fifteen under-sluices are built in the dam, in the river portion: each $8' \times 4'$, with their sills $12\frac{1}{2}$ feet above the bed of the river, and designed to carry off the early monsoon floods, which are heavily laden with silt. Two additional sluices to draw off the water at higher levels for the canal supply are built, one in the north and the other in the south flank, each $3' \times 3'$, with their sills respectively 24 and 50 feet above the sills of the under-sluices.

32. Seven turbine sluices, *i.e.*, two on the right and five on the left bank have also been provided, each $2\frac{1}{2}$ feet diameter.

33. The line of the dam crosses the river in a curve of 4,500 feet radius convex to the water, the length of the curve being 2,300 feet; it is continued on the north bank, in a line tangential to the curve, and on the south a reverse curve of 300 feet radius for a length of 407 feet brings the line to the ridge along which it is taken in a straight line tangential to the last curve, the length of 400 feet at the south end giving an excellent site for a waste weir. The curved plan of the dam was adopted to suit the best line of foundation and not with any idea of giving additional strength. This form however adds considerably to the beauty of the structure and gives an appearance of greater strength. A light railing 3′ high is provided on each side of the roadway along the top of the dam. It consists of C. I. standards fixed in the parapets, 10′ apart, and supporting a double line of W. I. piping.

The cross section of the dam.

34. In the original design the section was calculated for a maximum height of 101 feet with top width of 13·65 feet, bottom width 67·64 feet, and the down stream profile in three straight batters. The dam was to be of rubble masonry, the weight of which was assumed in the calculation at 140 lbs. per cubic foot.

In 1883 the design was revised and the conditions laid down were that the intensity of vertical pressure was to be nowhere more than 120 lbs. per square inch: that the resultant pressure was to fall within the middle third of the base of any portion of the section, and that the average weight of the material (rubble masonry and concrete) was to be taken at 160 lbs. per cubic foot. This weight was decided upon after a number of experiments with samples of the materials that it was proposed to use. Thus the average weight of stone was found to be 183 lbs. per cubic foot, some specimens (generally boulder stone) weighing as much as 190 lbs. per cubic foot. Old mortar was found to weigh 134 lbs. and concrete made of gravel, metal and mortar 154 lbs. per cubic foot. These results gave the weight of rubble masonry thus :—

	Lbs.
60 cubic feet of rubble at 183 lbs. = ...	10,980
40 cubic feet of mortar at 134 lbs. = ...	5,360
100 cubic feet masonry=...	16,240

or 162 lbs. per cubic foot. In the concrete, it was proposed to use about 20 per cent. of large rubble and the weight was calculated thus :—

	Lbs.
80 cubic feet of concrete at 154 lbs. per cubic foot = ...	12,320
20 cubic feet of stone at 183 lbs. per cubic foot = ...	3,660
100 cubic feet concrete=...	15,980

or 159·8 lbs. per cubic foot. The average weight was therefore taken at 160 lbs. to the cubic foot. In construction, the quantity of stone embedded in the concrete is over 25 per cent., and in the masonry the quantity of rubble is also in excess of that estimated. The weight therefore assumed in the calculations errs on the side of safety. It may be noted that the weight assumed in the calculations for the Tánsa Dam is 150 lbs. to the cubic foot, and in the case of the Quaker Bridge Dam, to be built for the water-supply of New York, the weight was determined by experiment, and found to be 156·25 lbs. per cubic foot. In the Vyrnwy Dam the actual weight of material is 160·8 lbs. per cubic foot, and in the Ternay Dam in France the assumed weight was as high as 167 lbs. per cubic foot. The section according to which the dam has been built is shown in Plate No. 15. The water face has a batter of 1 in 50 and the profile of the down stream face is a series of straight batters for every 10 feet height, the general curve being a catenary. In submitting the revised design for sanction Mr. Whiting, the Executive Engineer, remarked as follows on the design :—

"The section has a curved profile on the down stream side, for which a catenary has been adopted, because it is easily drawn and will be easily checked on the work by hanging a light chain so as to pass through any three points already built. The dam was first designed in sections 10 feet in height after the French method, so that the resultant should in no case transgress the boundaries of the middle third of the base of each section and also

that the maximum vertical pressure should never exceed 120 lbs. on the square inch. The drawing was then placed vertically and a light chain hung, so as to touch all the lines forming the contour of the consecutive sections. It is clear that since a catenary becomes flatter towards the base it is so far adapted for profiles of dams, but its chief merit is that it requires no calculation. The process described above was repeated several times, and after many trials it was found that the best results were obtained by starting at highest flood level with a width of 12½ feet and with a weight above that equal to that of the road and its walls, a circular curve of radius 42½ feet was used to join the catenary curve to the face of the top wall which is vertical."

In practice, however, it was found easier to build according to the designed straight batter and to check the width from a fixed setting-out line; the general appearance is a curve as it is difficult a detect where the changes of batters occur. As a matter of curiosity, the profile has been checked by means of a chain, and it was found to correspond generally to the catenary, but this method could not be used with accuracy for building purposes. Looking at the section on Plate No. 15 it will be seen that on the up-stream side, at the sill level of the sluices, an increased width of 4′ is provided. This is to take the piers between the sluices to carry the lifting gear at the top of the dam, also to give room for the protective screens, and to provide a pathway to give access to the front of the sluices. The fact that the introduction of the openings for the under-sluices would intensify the pressure in the section between them also rendered an additional width advisable, and this was taken into consideration in the calculations. The section was worked out for a height of dam of 103 feet; in those places in the river, where the extra depth of foundations produced a slightly greater height than this, the last batter, *viz.*, 9·3 in 10 was continued, and the first few courses at foundation level were laid somewhat in excess of the calculated width. The maximum pressure, *viz.*, 117 lbs. per square inch, occurs at up-stream toe, reservoir empty. In this diagram two sets of figures are shown for the intensity of pressure at the down-stream edge of each section. The upper figures are the results of the calculation by the ordinary method, and the lower denote the corresponding results arrived at by Bouvier's theory, the latter being considerably in excess of the former. The mortar used in the work is known to have a crushing strength, when one year old, of fully 700 lbs. on the square inch; therefore the factor of safety in the case of both calculations is very large. In the Quaker Bridge Dam the limit adopted in the calculation was 233 lbs. on the square inch, the mortar to be used being made of cement; also many existing masonry dams in Europe, built of lime rubble masonry or concrete, give much higher pressures than will ever obtain at Bhátghar, as the following figures show :—

Villar	Dam	(Spain)	150	lbs. per square inch	on up-stream toe
Gileppe	„	(Belgium)	150	„ „ „	down-stream toe
Alicante	„	(Spain)	171·	„ „ „	„
Ban	„	(France)	155	„ „ „	up-stream toe

The final sanctioned section for the Bhátghar Dam was designed, and all the calculations worked out, by Mr. A. Hill, Fellow of Cooper's Hill, Assistant Engineer, under the orders of Mr. Whiting, the Executive Engineer, and a note by Mr. Hill on the method adopted in these culculations is given in Appendix No. VI.

Foundation.

35. The site selected was, in the first place, opened out as much as practicable along the whole length, so as to ascertain that sound rock was available everywhere, special caution being necessary in the river crossing, where there would be a heavy overfall from the under-sluices. The trial trenches which were carried deep into the rock in the river bed discovered the existence of a layer of basalt, about 12 feet thick, overlying the trap and separated from it by a thin film of yellow clay. The rock itself was perfectly sound and of a most durable character, but as it was jointed and had not an even bearing on the rock below, it was decided to remove the whole of it. The quantity that had to be excavated was greater than anticipated, and in one place sound rock was only reached at a depth of 26 feet, giving a width of foundation of 74 feet. Close to the right bank of the river, the rock was found to exist in large cubes, separated from each other by joints of soft clay of varying thicknesses. Although the rock itself was of an excellent quality, the whole of the jointed mass was re-

moved until perfectly sound rock was obtained for the full width of the foundation, which occurred at a depth of 50 feet. The founds were stepped up towards the south, and good rock was met with until close to the junction of the small reverse curve with the main curve of the dam, where it dropped suddenly and was replaced by a soft red rock. This had to be excavated for a depth of 30 feet before a reliable foundation could be obtained; from this point to the end sound rock was found comparatively close to the surface. In the original design it was proposed to construct only one waste weir on the south bank, the length extending to the small reverse curve above referred to. The existence however of the soft red rock in this portion, where the overfall would have been very great, necessitated an alteration in the design, which has proved to be also a great improvement. The south weir was shortened so as to confine the overfall to the length where the foundation was good, and a second waste weir was designed at the north end of the dam, where excellent rock existed. Increased waste weir accommodation was thus obtained, and it was possible to provide the full required number of automatic sluice gates on the north weir that would have been impracticable on the south.

No difficulty was experienced in obtaining good foundation on the left bank, except at one point in the site of the north waste weir, where the rock was much fissured. It was therefore decided to build up the waste weir at this point for a distance of 50 feet, to prevent any overfall on the rock that appeared to be not sufficiently sound to resist it. The dam therefore has been founded throughout on a rock base, about the strength and soundness of which there can be absolutely no doubt. Before commencing work, every foot of the foundation was carefully tested, and in most cases holes were drilled into the rock 3 or 4 feet in depth, to be certain of its soundness. All levels and other information has been recorded on a foundation plan.

The construction of the dam.

36. In the original design, it was proposed to construct the dam entirely of rubble masonry. The excellent results, however, obtained from experiments with sample of concrete used in the main weir at Vir, resulted in the substitution of concrete for rubble masonry in the hearting of the dam, with the object of reducing the cost of construction. The result of a series of experiments with blocks (10″ × 10″ × 15″) of concrete at Vir showed that the average crushing weight was 400 lbs. on the square inch, and from similar experiments subsequently with the Bhátghar concrete the result was an average of 375 lbs. on the square inch. The proposal therefore was approved with the limiting condition that concrete was to be used where the pressure did not exceed 60 lbs. on the square inch. This method of construction has therefore been adopted, and the boundaries of the 60 lbs. pressure are shown on Plate No. 17.

The base of the dam, and where the pressure exceeds 60 lbs. on the square inch, is built of uncoursed rubble masonry, between faces of hammer dressed block in course masonry of thickness varying from 3′ to 15″, as shown on the section in Plate No. 15. In laying the foundations the rock at the down-stream toe was dressed throughout with a slope downwards towards the centre of the dam, and similarly at the up-stream toe it was dressed so as to be generally at right angles to the up-stream batter of face, of 1 in 50. The centre portion, on which either rubble masonry or concrete was laid, was blasted out so as to present a rough base everywhere, as nearly as practicable at right angles to the resultant pressure. The space between the side of the excavation for founds and masonry face on the down-stream side was all carefully filled with concrete up to the surface level of hard rock. In order to pass off the river discharge, during the construction of the lower portion of the work, a working sluice was built through the dam with its sill at river bed level. This sluice or culvert is 4 feet wide with a semi-circular arch and total height of 7 feet. When no longer required it was built up for a distance of 16 feet from the up-stream face. This portion of the sluice was built one foot wider than the remainder, and with stones projecting 6 inches so as to secure proper bond. A 4″ pipe with sluice at down-stream end was also laid in this 16′ of wall to pass off leakage from the mouth of the sluice which was temporarily blocked up during construction. The portion of culvert on the down-stream side remains

open, and will be used to give access to the bottom of a small shaft 3″ square, that has been built from the roof of the culvert vertically to the top of the dam. It is proposed to test the deflection of the dam by means of a plumb bob in this shaft, observations being taken when the reservoir is empty and afterwards with the full water pressure. The discharge however through the under-sluices during three seasons has resulted in the formation of a heavy bank of gravel and boulders about 50 feet from the dam, and a pool of water which completely covers up the working sluice; it will therefore probably be advisable to construct a small wall up to river bed level, with the double object of providing a water cushion or basin to protect the founds, and from which loose boulders can be excluded, and also from which the water can be pumped to give access to the culvert, to carry out the observations for deflection.

The work was begun in July 1881. By the end of June 1891 the whole of the main dam was completed with the exception of the top layer of the parapets, the hand railing and roadway. The south waste weir was built up to within 9″ and the north weir up to the finished crest level. The cubic contents of the dam and waste weir, when complete, will be 4,657,032 cubic feet, of which the following is a detail :—

	Total cubic feet.	Total cost.	Cost per 100 cubic feet.
		Rs.	Rs. a. p.
Rubble masonry	1,512,802	2,55,081	16 13 9
Face work	638,256	2,01,009	31 7 10
Concrete	2,505,974	3,95,123	15 12 3

The under-sluices.

37. The first mention on the records regarding the proposal to adopt under-sluices occurs in a letter from Colonel Fife, Chief Engineer for Irrigation in 1869, to Mr. Whiting, in which he suggests four plans for storage works, the third being :—" To form a reservoir on the main stream, but construct the dam with numerous under-sluices, that floods with their silt may be passed through it, and thus obviate the silt difficulty. The plan is a novel and untried one and certainly not so good as others, if they are feasible."

38. The scheme submitted by Mr. Whiting in 1871 provided for 25 under-sluices. Quoting from his original report :—

" The level proposed for two sluices (to let off water for irrigation) is 30 feet above the bed; but there is room for five and twenty at that level. If the extra sluices be adopted, the efficiency of the reservoir will be prolonged enormously. The combination of sufficient passages for the purpose now described, but with an ample weir, was suggested by the method proposed by the Chief Engineer for Irrigation, Poona, for employing under-sluicing when weirs are not available."

39. In 1877, in reviewing the project, the Chief Engineer for Irrigation Colonel (now General) Merriman, R.E., remarked as follows :—" Mr. Whiting's project for the Bhátghar Reservoir includes provision for extensive under-sluices designed to obviate the silting which is anticipated may take place owing to the small size of the reservoir as compared with the run off from the catchment basin. I may here observe that this very question arose when the Khadakvásla Reservoir was first submitted. It was then estimated to fill 38 times each season; and the objection on the score of silting was more or less completely met by the argument that silt, in the proper sense of the word, was not to be feared, as its quantity was proportionate to the area of the catchment basin; and that the catchment being comparatively small (196 square miles) it would take a very long period to produce any appreciable effect on the storage. This argument is applicable in proportionately greater force in the case of the Bhátghar Reservoir, where the drainage area is smaller. As regards the danger from pebbles, it was shown that this movement in the Deccan rivers was very

slow; and that, moreover, the deposit would take place entirely in the upper part of the reservoir, where the velocity would be checked, and that their removal would be effected with ease." Experiments were afterwards made to determine the actual quantity of silt held in suspension, during the early monsoon floods, and these proved that the maximum deposit was as much as 1 in 100. Subsequently silt experiments were made at Lake Fife, and although they proved that the deposit near the dam and in the body of the lake was very small, yet that at the head was undoubtedly very large and that the tendency would be for it to move forward every year. The result was that when the design for the dam was revised, Mr. Whiting's proposals were fully approved by both Mr. Hart, then Chief Engineer for Irrigation, and General Merriman, then Secretary to Government, Public Works Department.

40. In November 1884, the Inspector General of Irrigation visited Bhátghar and afterwards left on record a note in which he strongly condemned the under-sluices, as both "useless and dangerous." Government in consequence ordered a further inquiry to be made on the subject, and Colonel (now General) LeMesurier, Acting Chief Engineer for Irrigation, Mr. Whiting, Acting Superintending Engineer for Irrigation in Sind, and Mr. C. T. Burke, then Executive Engineer, Nira Canal, reported in full on the points raised by the Inspector General for Irrigation. The result of this inquiry was that Government decided that the sluices should be adopted on the grounds that they would be effectual in mitigating the evil of silt, and that the safety of the dam would not be endangered by them. It was however admitted that there would always be a risk of some of the sluices getting choked by debris brought down in flood, caught by the screens in front. Judging from the experience of three years, it is most unlikely, that any serious difficulty will ever be met with in closing the sluices whenever required, provided ordinary precautions are taken. The two dangers to be guarded against are (1) heavy timber (2) the accumulation of brushwood and branches of trees on the screen in front. The rails, placed horizontally in front of the sluices and one foot apart, are an ample and efficient protection against timber. As regards brushwood, it has been found that this frequently does accumulate on the rails, and on one occasion prevented one gate from being quite closed, as a root of a bamboo was caught and projected over the sill. The gate was closed without difficulty after a high flood had swept the obstruction through the sluice. It is found however that after the first heavy flood in July, the river is discharged through the sluices with a head of from 4 to 15 feet, and when it falls below 8 feet, the establishment employed during the monsoon to watch the sluices can always clear away all obstruction. The fact that it will always be possible to examine and clear the protective screens, before lowering the gates, is an important one and seems to have been overlooked in the discussions on the subject. It considerably reduces the risk of a failure to close the gates, when required, and makes such a calamity as complete loss of storage practically impossible.

During the three years that the sluices have been in operation, the water on two occasions rose to a height of 43 feet and several times over 30 feet above the sills, but not a trace of injury to masonry or to any part of the work is perceptible. The test of the first three years was an exceptionally severe one, because owing to the timber and bamboos in the area to be covered by water, when the reservoir fills, having been felled for use on the work, an unusually large quantity of brushwood, loose bamboos, &c., was brought down in floods. This evidence, together with the fact that sluices exist in dams in other parts of the world under greater heads than at Bhátghar, is sufficient to show that no injury to the masonry need be feared.

41. The arguments in support of the theory that the sluices will be effectual in prolonging the life of the reservoir are as follows. The year 1890 was an average one as regards the river discharge. The quantity of water, gauged to have passed through the sluices amounted to 30,000 millions of cubic feet, or nearly six times the content of the reservoir. Experiment has proved that during the first monsoon floods the silt held in suspension is quite 1 part in 100. If there had been no sluices, the reservoir would have filled, when the floods were most heavily laden with silt and subsequently the water would have been discharged by the waste weir, after the greater proportion of silt had been deposited

in the lake. It is therefore probable that silt to the extent of at least 1 in 500 would have been left in the reservoir, which at this rate would be silted up to waste weir level in 80 years. The sills of the sluices are 12 feet above the bed of the river, the fall of which is 5 feet a mile. From observation it is found that in ordinary years the floods will be discharged with an average head of 15 feet, and water will be ponded up for a distance of 3 miles above the dam; consequently a certain proportion of the heaviest silt will still be left in the reservoir, owing to the velocity of the floods being checked, but the distance from the sluices being so short, there is not sufficient time for the silt to be deposited and the greater portion will be carried off. The estimate that $\frac{2}{3}$rd of the silt that would otherwise be deposited in the reservoir will be passed through the sluices is probably a low one. The fact also remains that the area of the back-water above the dam during the monsoon, when the river is discharged with an average head of 15 feet, is less than $\frac{1}{30}$th of the whole area of the reservoir, and, therefore, at the time when the greatest amount of silt is held in suspension, $\frac{29}{30}$th of the whole area is uncovered, and consequently no silt can be deposited there. The minor danger therefore only remains from pebbles, gravel, and heavy particles left at the point where the check must occur. Judging from the way in which the large scouring sluice in the main weir at Vir has acted, it appears more than probable that eventually, when the basin has silted up to sill of sluices at Bhátghar, a new river bed will be formed extending possibly for 6 or 7 miles above the dam, and an equilibrium will be established, the silt deposited in one season being brought forward and carried along the new channel till it is passed through the sluices, the result being that silting up will be confined to the area up to the 15′ contour and the main body of the reservoir will always be kept clear.

When the plans for the Bhátghar Dam were revised, it was decided to construct 17 sluices, with their sills 12 feet above river bed, instead of 25 at a higher level as originally proposed. Subsequently when it was found that the rock close to the left bank was of inferior quality, the number was reduced to 15, so as to avoid an overfall on the unsound rock.

42. The design for these sluices is shown on Plates Nos. 19 and 20 and requires little additional description. The clear opening is 8 feet high and 4 feet wide; each gate of C. I. with its steel lifting rod $4\frac{1}{2}$″ diameter weighs about $4\frac{1}{2}$ tons. The top length of the lifting rod is square in section for a length of 12′-6″ machined on all sides, to work in a square guide also planed true. The top 11′-4″ of the rod is screwed, and on it fits a gun metal nut and collar which fits in a cast-iron thrust box, bolted to the masonry at the top of the dam. A cast-iron capstan head fits the nut, and is worked by six W. I. arms, the end portion of which are bent so as to be horizontal at a suitable height above ground level. Additional leverage can be obtained by means of W. I. piping, slipped over the ends of the bars. The screen in front of each gate consists of W. I. double headed rails $2\frac{1}{2}$′ from the face of the sluice weighing 66 lbs. to the yard, fixed in horizontal rows, 1′ apart, the ends resting in grooves in the block in course masonry piers, and kept in position by vertical bars $1\frac{1}{4}$″ diameter. The calculated maximum velocity through the sluices is 60 feet a second, and it is estimated that the greatest probable pressure on each rail will be less than $\frac{1}{3}$rd of the safe load, and $\frac{1}{15}$th of the breaking load; the margin of safety is therefore very large. The only defect to be noted in the design is the position of the cage of rails with respect to the sluice. It should have been at least 12 feet in front instead of only $2\frac{1}{2}$ feet. This could have been done at some extra expense by prolonging the piers up-stream, and the cage at this distance would have minimised the danger of brushwood interfering with the working of the gate. The gates with the lifting rods, excepting the top screw length, were constructed by Messrs. Richardson and Cruddas of Bombay, each gate being carefully tested. The two sluices for drawing off water for irrigation at R. L. 266·20 and R. L. 292·20 are each 3′ square and similar in design to the under-sluices. A great mistake was however made in these two gates by providing brass facing on the gate only, the frames on which they work being only planed cast-iron. The result in two seasons is that the faces of the frames are pitted by rust, and there is no doubt that eventually brass faced frames will have to be substituted. The object of their omission of the brass on the frames was economy, but the saving effected was only about Rs. 200 on each sluice.

The waste weir.

43. The catchment area of the reservoir is 128 square miles, with an annual rain-fall varying from 250 inches in the ghâts to 40 inches at the dam site. The maximum run off assumed in the case of Lake Fife with a catchment similarly situated, but 190 square miles in area, was ½ an inch per hour, and on only one occasion has a flood been known to approximate to this estimate. For the smaller area at Bhátghar therefore the maximum run off was assumed at $\frac{5}{8}$" per hour, equal to a discharge of 51,200 cubic feet per second, which is considerably in excess of the highest known flood calculated from observations of the river discharge, and nearly double the largest flood, gauged since the commencement of the work.

The weir is divided into two portions, one in the north, the other at the south end of the dam, and in order to accommodate the road over the dam, both weirs are crossed by means of piers and arches, the clear width between piers being 10 feet. The number of openings on the north is 45 and on the south is 36, the maximum depth of discharge allowed above crest being 8 feet. For broad crested weirs, with a clear overfall and complete contraction at both ends, the discharge is obtained from the formula.

$$D \text{ (in cubic feet per second)} = 0{\cdot}385\ L. \times H. \sqrt{2\cdot g.\ H.} = 3{\cdot}09\ L. \times H. \sqrt{H}.$$

For an opening 10 feet wide and depth of discharge 8 feet D = 697 cubic feet per second.

For the 81 openings the discharge therefore is 56,457 cubic feet per second, somewhat in excess of the assumed greatest possible flood. It is found from the experience of many years, that the highest floods are those due to the S. W. monsoon rain-fall occurring between June and the end of August, that is, when the 15 under-sluices will be open and capable of discharging 26,000 cubic feet per second. Under these conditions the maximum flood would be discharged through the under-sluices and with a depth of 5½ feet over the crest of the weir. The only occasion therefore when the weir is likely to be brought into full operation is if a maximum flood occurs after the sluices are closed and the tank has filled, namely, during the late rains of September and October. It has hitherto been the practice to construct waste weirs of reservoir so as to remain always open, the level of the available storage thus being that of the crest of weirs. The section of the dam however has to be designed sufficiently strong to withstand the full head of water, up to the level of highest flood discharge over the weir. The height therefore between weir crest level and highest flood discharge is wasted as regards storage. This extra quantity will be secured at Bhátghar by closing the opening between the piers on the weirs when the monsoon floods have ceased, by means of gates.

44. In the design, which was revised in 1887, the proposal was to close the 45 openings on the north weir by falling gates which would fall open automatically when the water in the reservoir reached a certain level. The 36 openings in the south weir it was proposed to close with steel needles invented and patented by Mr. Whiting, then Executive Engineer.

In order to test the efficiency of the falling gate, an experimental one 8′ high by 4′ wide was erected in the main weir at Vir. This shewed that, with some improvements in details, the gate would fall open automatically; the great objection to it however was the very great difficulty experienced in closing it. One or two serious defects were subsequently brought to light and shewed that, in the existing form, it would not be safe to adopt it on such a large scale as at Bhátghar. In 1889 Mr. E. K. Reinold invented and patented a sluice gate on a new principle, the general description of which, together with the result of the experimental gate erected at Vir, is given in Appendix No. VII, which also contains the report of the Committee appointed by Government to test and report on the new gate. The reasons for abandoning the steel needles in favour of gates on the south weir are given in the same report. It has therefore been finally decided to adopt Mr. Reinold's gate for both weirs, those on the north weir being arranged to work automatically. The general design for these gates is shown in Plate No. 23.

APPENDIX No. I.

Minute by His Excellency the Governor of Bombay, dated 22nd March 1890.

One of the largest public works in progress during my tenure of office is the Nira Canal in the Poona District. Having visited the works and having watched their progress with great interest, I desire to record some observations regarding this important project and the services of the officers who have been connected with it, and to add some remarks on the general question of the extension of irrigation in the Deccan and Southern Marátha Country.

2. The project owes its inception, like nearly all those yet undertaken in the Presidency, and all the more important of those yet undertaken in Sind, to Lieutenant-General J. G. Fife, R. E., formerly Chief Engineer for Irrigation, under whose orders the original survey for a project in the Nira valley was commenced in 1864, and who finally reviewed the designs and estimates for the complete work in 1872 in the form in which they were originally submitted to Government in 1877.

3. The district traversed by the works, comprising a portion of the Purandhar, the southern portion of the Bhimthadi, and the southern and eastern portions of the Indápur Tálukas, is one of very uncertain and capricious rainfall, so much so, indeed, that there is frequently a failure of crops for several years in succession, and it has fitly been termed a drought-stricken district.

4. The works are described in a report, which has been specially furnished for the purposes of this Minute, as follows :—

(*See* Report for full particulars).

5. The earthworks of the Canal were first undertaken during the famine 1876—78, but there was subsequently some delay in proceeding with the project as an ordinary work, and it was not until 1881 that it was sanctioned as a whole and its cost ordered to be met from the Famine Insurance Fund, it being classed as a Protective work.

6. At the close of the year 1884-85, the main weir at Vir was built up to within three feet of the designed height, and the main Canal was practically completed up to the 33rd mile. At the end of the current year the whole Canal, for a length of 101 miles, will be completed, and all distributaries up to and inclusive of No. 58 in the 91st mile will be in full operation. The dam at Bhátghar, which at the close of 1884-85 had been raised 20 feet above the river bed, was in 1889 raised so as to secure a storage of 63 feet, representing in volume 2,000 millions of cubic feet; and by the end of this year it is anticipated that it will be raised so as to provide storage after next monsoon up to waste weir crest level, or 37,000 millions of cubic feet.

7. Up to the end of 1884-85 the total expenditure had amounted to 27 lákhs; in the subsequent 5 years Rs. 19 lákhs have been spent, and the balance of the sanctioned estimate remaining unspent will be Rs. 2 lákhs only.

8. The Canal was opened in 1885 and has since irrigated the following areas :—

	Area irrigated.	Area commanded.
	Acres.	Acres.
1885-86	11,195	59,685
1886-87	4,462	71,190
1887-88	5,528	84,129
1888-89	18,559	116,414
1889-90	16,000*	136,000

* Approximate.

In the first year the water was given free; in subsequent years it has been charged for at a low scale of rates.

9. The works are of an importance and of a character in design and execution of which any country might be proud. They reflect the greatest credit on the whole of the officers employed on them, but chiefly on Mr. J. E. Whiting, M. A., M. Inst.C.E., late Acting Chief Engineer, C.D., who was first employed on the survey of the project in 1868 and designed the works as originally submitted in 1872 under General Fife's orders. The details have since, as is natural, undergone some modification, but substantially the design as a whole and in respect of the more important details is Mr. Whiting's, who has further had a large share in the supervision of their construction. The following are the names of the several officers principally concerned.

(*See* Statement at end).

10. To the whole of these officers and subordinates the thanks of Government are due, and it is a pleasing duty to me to place on record my personal appreciation of the services of those who have been employed on the project during the past five years. I do so with some knowledge of the difficulties that have had to be met, many of which have come before me from time to time in transacting the business of the department, and of the isolation and discomfort to which the officers have been exposed by protracted residence in the districts in which the works are situated.

11. Up to the present time the storage works at Bhátghar being incomplete, the supply of water in the Canal has been restricted to monsoon and rabi irrigation, and there has been no room for that development of the irrigation and revenue which may be expected to follow when the supply is rendered perennial and opportunity is afforded for the cultivation of the more valuable crops, such as sugar-cane, garden crops of all classes and the valuable hot weather fodder and grain crops.

12. It is difficult to gauge the importance of the work even in its incomplete state by figures, but the expansion of irrigation in 1888-89, a season of deficient rainfall, is an indication of its effect on the material prosperity of the people. The total rainfall varied from 11·58 to 19·84 inches. The effect of the work in supplying water for drinking as well as agricultural purposes to the arid tract of 182 square miles, comprised in a district, extending over a length of 55 miles from Vir to Nimbgaon at the 90th mile of the Canal, can hardly be overstated. The benefit to agriculture is represented by the value of 18,559 acres of irrigated cultivation, which is estimated at over Rs. 5 lakhs; and with such a deficient rainfall, it is not (as remarked in the Resolution on the Revenue report) an exaggerated view to give the works credit for the whole value of the crops irrigated. Water was given free to 3,846 acres out of this total, and the water-rate assessment on the remaining 14,713 acres averaged only Rs. 1-6-0 per acre. These figures show that every encouragement is being given to the rayats to avail themselves of the means of irrigation which the work affords, and I think that Government are acting wisely in offering such inducements in the first stages of the progress of irrigation on a large new work.

13. Considering the character of the works and their past history, the expansion of the irrigation on all the works of recent construction in the Deccan and Gujarát in the last two years must be said to be highly satisfactory. The figures for five years are as follows:—

Year.	Acres.	Approximate average rainfall.
1885-86	59,450	22·92
1886-87	42,628	28·81
1887-88	46,187	26·35
1888-89	79,195	19·65
1889-90	85,000*	23·73

* Approximate.

14. Two steps of great importance to the financial future of the works have been taken: *1st*, the working expenses have been considerably reduced by economy in establishments, and *2nd*, the water-rates have been raised to a more real proportion of the value of the water. This latter step took effect generally from 1st April 1889, and the figures for 1889-90 show that the measure had no deterrent effect on the expansion of irrigation.

15. These facts give the promise of great improvement in the direct financial results, and I trust it may be such as to induce the Government to undertake further well-considered projects of the same character as the Nira and Mutha Canals. The improvement in railways and communications cannot fail to stimulate the demand for works affording the means for increased production, and I would venture to strongly urge that a supply of water to render a large proportion of the cultivated area independent of the vicissitudes of rain-fall, and at the same time to afford means for raising the more productive crops which cannot be cultivated without artificial irrigation, is an essential element in any programme for the development of the material resources of the country deserving the attention of Local Boards as the representatives of agricultural interests.

16. Financial exigencies are such that it is impossible to hope that Government can embark on a large expenditure for this purpose without the prospect of a return; but I would urge that, as regards the Deccan in particular, strictly commercial principles should not be pushed to an extreme: that the capital and revenue accounts should not be burthened with fanciful book charges, and that the indirect advantages which such works confer should have great weight in determining the question of their advisability.

REAY.

LIST OF THE NAMES OF THE PRINICIPAL OFFICERS AND SUBORDINATES WHO HAVE BEEN EMPLOYED ON THE CONSTRUCTION OF THE CANAL.

Chief Engineer for Irrigation.

Lieut.-General Fife, R.E., Superintending Engineer for Irrigation—From 25th February 1867 and Chief Engineer for Irrigation—From April 1867 to March 1876.

Lieut.-General Merriman, R.E., C.S.I.—From May to November 1875, and again from March 1876 to August 1877.

Mr. J. H. E. Hart, M.Inst.C.E.—From September 1877 to September 1887.

„ J. E. Whiting, M.A., M.Inst.C.E.—From June to July 1887, from October 1887 to January 1888, and from May 1888 to May 1889.

Assistant Chief Engineer for Irrigation.

„ W. C. Hughes, M.Inst.C.E.—From October 1868 to April 1880.

„ W. H. LeQuesne—From April 1880 to May 1887.

Executive Engineers directly in charge of the Nira Canal Works.

Mr. J. E. Whiting, M.A., M.Inst.C.E.—
- From November 1876 to March 1880.
- „ October 1880 to June 1883.
- „ October 1883 to May 1884.
- „ January 1886 to June 1887 and August 1887 to September 1887.

Mr. C. T. Burke, B.E., M.Inst.C.E.—From June 1884 to January 1886.

„ W. H. LeQuesne—From July to October 1882 and May 1888 to date.

Assistant Engineers.

Mr. G. A. Bhat, M.A., L.C.E.—From February 1877 to November 1878.

„ G. K. Apte, B. A., L.C.E.—From April 1879 to April 1880 and from February 1881 to January 1883.

„ A. Hill—From July 1881 to September 1887.

„ W. L. Strange—From November 1880 to February 1882.

„ C. N. Clifton—From June 1883 to February 1885.

„ S. N. Squire—From November 1881 to April 1886.

„ H. F. Beale—From November 1882 to June 1883, July to October 1886, September 1887 to date.

Principal Upper Subordinates.

Ra'o Baha'dur Rawji Trimbak—(Since retired).

Sub-Conductor D. Henry—(Since deceased).

Mr. Rukhmaji Narayan—

„ Ganesh Janardan—

„ Samson Abraham.

„ P. J. Fernandes.

„ Narayan Vishnu Barve.

APPENDIX No. II.

ABSTRACT OF THE PRINCIPAL SPECIFICATIONS FOR THE WORK ON THE BHATGHAR DAM.

Mortar.

1. The mortar for concrete and masonry is to be prepared as follows :—

2. Well burnt hydraulic lime is to be placed in the ghanies (*i.e.*, the ordinary native mortar mill with stone wheels) in an even layer and to be well sprinkled with water, but not drowned, unless the lime be of such a nature that it will not slake without being flooded with water at first, and for this special orders must be obtained from Executive Engineer.

3. After an hour it is to be wetted thoroughly ; at the end of two hours it is to be stirred up and then covered with water and allowed to slake for two hours more ; in all five hours slaking, after which all unslaked lumps are to be removed. It is then to be ground for three hours, water being added whenever it becomes stiff.

4. Thoroughly wetted sand is then to be added evenly throughout the ghani in the proportions of two of sand to one of slaked lime.

5. The sand and lime to be ground together for two hours ; in all five hours grinding.

6. The mortar to be scraped up occasionally to prevent the sand from caking on the bed of the ghani.

7. The mortar turned out of the ghani is to be made into a square heap about 9″ deep for measurement.

8. If it is not used within 6 hours, it is to be heaped up about 3 feet high, with water standing in a pool on the top. Mortar used after 12 hours is to be hand—mixed before being carried away. No mortar more than 24 hours old is to be used for the face work and none over 48 hours for concrete. Mortar more than 48 hours old is to be unconditionally rejected and removed from the site of the platforms.

Specification for mortar ground in iron mills, driven by steam.

1. The lime is to be slaked in pans of such a size that the layer will not be more than 9″ thick. Each pan to contain 5 cubic feet, which is the quantity required for the outturn of one mill.

2. After 5 hours slaking the lime is to be picked, all under—burnt kunker being removed, and the grinding is to be done as follows .—

3. The four mills will keep in continual uniform motion, doing each 18 revolutions per minute, which with two wheels amounts to 36 grindings per minute in each.

4. Two adjacent mills are first to be filled with slaked lime (this operation takes 2 to 5 minutes), the lime is then to be ground for 5 minutes clear, after which the sand is to be added, picked and well wetted as usual (this operation takes 5 minutes) ; after all the sand has been put in, the grinding is to continue for 3 minutes clear, after which the mill is to be emptied (this operation takes 5 to 10 minutes) ; the time of grinding the lime must be watched with the greatest care, for it is important that the time specified should not be *decreased*. It is equally important that the time of grinding on the combined lime and sand should not be *increased* above that specified. While the sand is being put into the first set of mills, the lime is to be filled into the other set. In all there are at least 468 grindings, *i.e.*, the two wheels in each mill together revolve over the mortar 468 times.

Comparison with three wheeled ghanies (i.e., three stone-wheels worked by bullocks).

During the 5 hours grinding the three stones together revolve over the mortar 432 times as a maximum, against 468 as above.

Masonry.

The masonry to consist of rubble stone of a durable nature laid in mortar of hydraulic lime and clean sharp sand and to be of the following classes :—

1. The casing is to average from 3 feet thickness to 12″ thickness according to the designed section of the Dam and to consist of block in course rubble laid at right angles to the face and coursed rubble. The height of the courses in the face work is to be not less than 7″ and no stone to be less in breadth than one foot, or less in length than one foot. The stones to have parallel joints and beds rough-tooled true and square for at least the distance in from the face as the thickness of the course in height, but with face and back left rough. The face work to bond into coursed rubble, each stone of which is to be of full depth of the course and to have parallel beds, but with side joints of any form and fitted together as closely as possible.

2. The stones in alternate layers of the block in course rubble must break joints and bond in every direction. All stones to be well wetted before laying in mortar, and then driven down and into contact with adjacent stones by a light mallet.

3. The spaces between the stones, excepting the face stones, to be filled with mortar, and wetted pinners to be inserted so as to save mortar and increase the weight of the masonry, but no packing chips under stones are to be allowed.

4. The face joints to be neatly struck with a trowel, but not pointed or raised.

5. The back of the rubble is to be built, so as to bond at least 6 inches into either uncoursed rubble or concrete as the case may be.

6. The uncoursed rubble in the interior to consist of flat bedded stones carefully laid on their proper beds and solidly bedded in mortar, chips and spauls of stone being wedged in, wherever necessary, so as to avoid thick joints of mortar, care being taken that no dry work or hollow spaces are left any where in the masonry. No chips to be packed under stones to form their beds. The surface is not to be brought up to a uniform level, but the work is to be left uneven and bedded and driven home stone upon stone with a light mallet.

7. All stones, pinners and spauls to be well wetted immediately before laying. The uncoursed rubble is to be laid and bonded closely into the casing as soon after the latter is built as possible, and is to be laid horizontally between the inner edges of the casing, and is to be used as filling in all parts of the dam that may be subject to more than 60 lbs. of pressure per square inch.

Concrete.

1. The concrete to consist of broken stone and clean gravel or shingle intimately mixed with mortar of hydraulic lime after having been well wetted. The materials to be of all sizes up to what can be conveniently turned over and rammed, generally 3″ maximum for metal and gravel and ½″ minimum for gravel. The proportions should be chosen so that all interstices are filled up completely and the mortar just creams up on being rammed for three hours with rammers as heavy as can be continuously used by labourers (varying from 9 lbs. to 20 lbs.).

2. The mortar will consist of two parts of sand and one of slaked lime; and the usual proportions of the concrete will be:—

·4 Metal.
4 Gravel.
·3 Mortar { 2 sand. / 1 lime.

3. The concrete is to be laid in courses equal to those of the face work (average of 10″) on alternate days, the adjacent masonry being well wetted and the concrete carefully worked up by stakes, so as to join it closely. The edges of the masonry should be plastered with from ½″ to 1″ of mortar after having been wetted, in order that the concrete may unite with it firmly.

4. Heavy stones and boulders to be inserted in the concrete as it is being laid, with their thick ends downwards and to project beyond the upper surface of the layer, so as to bond that layer with the next above, and also to add to the weight. They should generally form ⅓rd part of the whole and should be well wetted before being laid. They should be placed, so as to allow free ramming between them.

5. The concrete will generally be laid in two layers, the 1st to be rammed for at least 20 minutes and the 2nd up to 3 hours.

6. All masonry and concrete is to be watered constantly from the moment that the mortar in it sets sufficiently to allow of water being thrown over it.

Masonry Arching.

1. All stones to be of good quality and to be roughly dressed to the right form, the course on the bed joints laid in ½″ joints of mortar made with good hydraulic lime.

2. The arch quoins to be of the same thickness as the sheeting of the course, being superior selected stones, in all cases extending right through from intrados to extrados, and alternately not less than 12″ and 18″ long upon the intrados face.

3. No stone to be less than one foot long and alternate stones to bond well into the backing.

4. Every third stone to be of the full depth of the arch.

5. Every stone to be struck side ways with a mallet, so as to leave no interstices, and all face joints struck neatly with a trowel.

6. The work to be well watered constantly.

7. The mortar to be fresh and as specified for rubble masonry. The soffit joints and face work of arch stones to be neatly struck and finished off with the trowel, but not pointed.

8. Key stones to be first fitted in, then taken out, smeared over with mortar made with fine sand, replaced and driven well home with a mallet.

Waste weir arching.

The above specification is valid for the two outside arch rings, the internal arching to be of a rougher description, the joints being only roughly chisel dressed and up to ¾″ thickness allowed.

Note on materials and work construction.

The stone used in the dam is of two kinds, *viz.*, from surface trap boulders and best grey trap from quarries. The former is known to possess all the qualities of the best possible building stone, and is practically imperishable. The quarried trap on the contrary is of most uncertain character and the test of time is the only one to show its durability.

Immediately on beginning the work quarries were opened at different places, and two, one on the south and one on the north bank, gave promise of good building stone. Specimens of the best kinds were laid aside in an exposed position, and for 5 years nothing but the best boulder stone was used in the face work, the quarried stone being worked into concrete, and in the rubble in the interior. When after exposure for 5 seasons the stone showed every sign of being sound and durable, it was also used in the face work after being carefully selected. In the faces and arching of all the sluices, and in the down stream faces of the two weirs only the best boulder stone has been used.

The mortar was made of lime and sand in the proportion of 1 of the former to 2 of the latter (*vide* Specification). The lime was obtained from "kunker" or the nodular lime stone common throughout the Deccan, but differing in character from that used in the head works at Vir. The Bhatghur kunker was found in large quantities below the surface of the ground at distances of from 3 to 6 miles from the works and had to be quarried. It was found in larger nodules than at Vir; also it was more mixed with soil and other impurities. Compared with the Vir lime, that obtained from the Bhatghur kunker is not so strong, is more difficult to burn uniformly, sets more slowly, and is less hydraulic. The results of the mortar tests, however, prove that the lime is decidedly good, that used at Vir being quite exceptional.

In 1888-89 when the work was rather more than half completed, it was decided to bring burnt lime from Vir; and owing to the low cost of collection of kunker, the very small loss in burning and a good road, it was possible to deliver it at Bhatghur at a less cost than that burnt close to the work. The lime at Bhatghur was burnt in the ordinary intermittent kilns, the sizes varying from 500 to 2200 cubic feet. The larger ones were turned out in 30, and the smaller ones in 15 days. One perpetual kiln was tried as an experiment and proved very successful, the outturn from it was on the average 83 cubic feet every 2 days. The fuel used in lime burning was charcoal, coke and refuse ashes obtained from the G. I. P. Railway. The usual proportions were :—

4 maunds (16 cubic feet) of charcoal + 2½ maunds (8 cubic feet) coke + 3 maunds (6 cubic feet) ashes to every 100 cubic feet of screened kunker. All the fuel was broken up as small as possible, then thoroughly mixed with the kunker.

It was found that the use of coke and ashes greatly improved the lime, by strengthening it, and making it set more quickly than by using charcoal alone. The charcoal was made chiefly from the "jambhul" jungle, in the land taken up for the reservoir, and although not so strong as that made from "babhul", proved to be very suitable for the purpose of lime burning. The greatest care, and constant supervision was required in burning lime at Bhatghur, especially at the beginning of each season after four months of the monsoon, when all work had to be suspended, as the results varied with the state of the kunker, according as it was damp or dry, and to the direction of the wind. No lime was however used at the beginning of the season, until it had been proved to be good by passing the prescribed test, which was as follows.

Briquettes (2" and 3" cubes) were made of the mortar in the usual proportions. They were allowed to remain in the moulds and kept damp for 24 hours; they were then taken out, and covered up with wet sand, kept damp for 24 hours. They were then removed and placed in water. If they kept their shape and continued to set, the lime was passed as good hydraulic.

Briquettes that passed this test were allowed to remain in water for not less than 6 months, and subsequently crushed in the mortar testing machine to arrive at the compressive strength of each specimen.

Briquettes were made regularly every day of the mortar used in the work, and on each specimen was recorded the date and the number of the kiln in which the lime had been burnt. The results of the mortar test show the compressive strength to be on the average 700 lbs. on the square inch. The maximum ever attained in one specimen was 1400 lbs. on the square inch and many specimens bore over 900 lbs. per square inch before crushing. After 10 days only, the mortar was found to stand generally 70 lbs. on the square inch. As instances of early tests may be mentioned one specimen of mortar with Vir lime, made at Bhatghur in the steam mortar mills, only four months old, and stood over 500 lbs., and another similar briquette, about the same age, which stood over 400 lbs. on the square inch before crushing. In comparing these results with those obtained on other works, it should be noted that the proportion of sand to lime in the Bhatghur mortar was 2 to 1.

Sand.

The sand for the mortar was obtained from the bed of the Nira river close to the work, and from different places varying from 1 to 3 miles distant. Such a thing as "clean sharp sand" does not exist in the Deccan; it is, as a general rule, disintegrated trap rock, mixed

with particles of kunker, murum, and quartz, all worn and rounded. At Bhatghur, after the first year's work, it was impossible to obtain clean sand, and washing had to be resorted to; the result, however, is a fair sample of the ordinary Deccan sand. The washing was done in a series of masonry pans or "howds" built in the bed of the river below the dam. A low wall was built across the river, forming a small pond, which was fed from the storage above the main dam. On the down stream side of this wall were built a series of pans 20′ × 10′, paved with stone, each being supplied with the required amount of water from the pond by a notch in the wall. The quantity and quality varied every year, and the greatest care and constant supervision in the washing was necessary to maintain the required supply of clean sand, and it is to the unremitting attention paid to its quality as regards size and cleanliness that the excellent results from the mortar are due. The mortar was ground in the ordinary stone mortar mills of the country for rather more than half the work, when steam mills were introduced. The chief objections out of a great many to the native method of grinding by bullocks are the great space required for a large number of mills, and the length of time required for the grinding. For a large daily and regular outturn of mortar these mills are most clumsy, and a source of continual anxiety to the engineer in charge of the work, and the only point that can be recorded in their favour is that they turn out good mortar, if carefully looked after. One of the greatest difficulties was the supervision of mortar grinding, which had to be done at night, when the bullock-drivers took every opportunity of shirking work. This was entirely obviated by a very simple and ingenious tell-tale designed by Mr. Beale, Assistant Engineer. One of the wheel poles or rails was made to drive, by means of a rod rivetted to it, a nut which worked on a central vertical screw about 15″ long. Each complete revolution of the wheel in the mill, caused one turn of the nut on the screw; the amount of grinding, therefore, was measured by the distance travelled by the nut. A certain distance was the standard for each outturn of mortar. When the nut reached the top of the screw, the bullocks were made to work in the opposite direction and so work the nut down again. That this check was needed was proved by the bullock-drivers striking work immediately it was introduced.

Grinding mortar by steam.

For the sake of economy in first cost, only a small size of mortar mill was purchased, *i.e.*, four mills with pans 7′ diameter. The result was in every way most satisfactory. When the mills were in full working order, the direct saving over the method of grinding by bullocks amounted to 6 annas per 100 cubic feet. The maximum daily outturn for the four mills was 900 cubic feet. With a larger size of mill, capable of turning out 25 instead of 15 cubic feet, the saving would have been very much larger. The steam mills also produced indirect savings in many ways—for instance, the bullocks previously employed for grinding mortar, were available for carriage of materials, the cost of which it was found possible to reduce. This reduction in cost of carriage was also due to the fact that the steam launch, which was used for bringing stones, charcoal and timber to the work, set free a large number of carts. One of the chief advantages of the steam mills, in addition to the economy in working, was the certainty of, and perfect control over, the outturn of mortar, the quality of which was proved to be in every way equal to, if not superior to, that made in the old way. As a proof of the working of these mills may be mentioned the fact that from the time they were put into proper working order, not a single specimen of the mortar failed to pass the prescribed test. It may be noted that in dealing with lime like that used at Bhatghur and Vir, the point of utmost importance is perfect grinding on the slaked lime *before* the sand is added.

Concrete.

The mixing was done by manual labour and by means of mixing machines, 5 of which were in use on the work. For mixing by hand flat masonry platforms were built at suitable places, and materials arranged in heaps on them consisting of layers of gravel, mortar and metal, each heap being turned over by means of a hoe, until thoroughly mixed. The mixing machines were most successful and the concrete made by them was generally more intimately mixed than that done by hand, the cost of the two methods being practically the same. The charge for a mixer was about 13 cubic feet, and each turned out about 600 cubic feet a day; considerable economy might have been effected by driving the mixers by steam.

During the early stages of the work, the carriage of concrete was done chiefly by cooly labour. When the work had been raised to the level of the ground near the north waste weir, a line of rails was laid on the dam, and connected with the line from the north quarry, and the work was supplied with all materials for long leads by means of trollies. Two concrete mixers were placed close to this line on a siding, and concrete was taken direct from the machine in trollies, and wheeled by coolies on to the work. The greatest difficulties occurred, when the work had been raised everywhere above ground level and when lift was introduced in addition to long leads. A ramp was constructed near the north waste weir, and a line of rails at a slope of 1 in 4 laid in connection with the original line from the quarry. The trollies were hauled up the slope by a steam winch, and wheeled on to the work by cooly labour. Wrought iron side tipping waggons were introduced at this stage and were made large enough to carry the contents of one concrete mixer and proved very successful. As it was found practicable to do only a limited quantity of work from the north tram line, owing to the width of dam being small, a lift was constructed on the down

stream slope of the dam, near the left bank of the river. This consisted of a timber staging, on which was laid a line of rails at a slope of 1 to 1 at first and subsequently ½ to 1, and the trollies hauled up by a steam winch, placed on the top of the dam, the height of lift varied from 50 to 66 feet.

Special under-tipping trollies were designed by Mr. Beale, the Assistant Engineer in charge, and made at the works under his directions. They consist of sheet iron boxes 5′ × 3′ × 2′ deep suitably strengthened with angle iron, resting on timber frames, provided with the usual trolly wheels and axles. The bottom of each box is attached to the frame on one side by hinges on which it swings freely. When closed, the bottom is kept in position by 3 pins attached to a lever fixed to a hinge at one end of the frame. When the trolly with its load reaches the top of the dam, the pins are withdrawn by means of the lever and the bottom swings back, allowing the concrete to drop clear on the dam; the bottom is then closed, and the trolly lowered. The concrete is removed to the work in the ordinary way. The actual working of this lift was very economical, but the cost of the staging and trollies brought the rate up to nearly the same as the tram line, and rather less than cooly carriage. This lift, however, enabled work to be done that it would have been impracticable to do in the same time in any other way, and caused a valuable saving in labour at a time when it was most scarce.

The whole of the work on the south flank was done by cooly carriage, as the leads were comparatively short, and tram lines would have been costly. When the dam had been raised to a height of about 50′ above river bed, considerable saving was effected by water carriage. A steam launch was purchased and used to tow barges which brought materials of all kinds direct to the work. Charcoal and timber from the land taken up for the reservoir were brought to the dam, the distance varying from 10 to 18 miles. The result was that a large number of carts were made available at low rates for carriage of other materials on the work.

Note on the Vir lime.

The lime used in the head works at Vir was obtained from nodular kunker gathered from the surface of the fields and banks of the river in the vicinity of the work. The best kunker is that which is found on the surface of a light yellow soil close to the river, also from *man* earth. Heavy rain washes away the soil, leaving nodules of kunker varying in size from a grain of gram to a walnut, free on the surface, enabling the collection to be done easily and cheaply, by simply brushing it into heaps, ready for carriage to the work.

The method of treatment is similar to that described in the Bhátghar specification for mortar.

The Vir lime was found to be much superior to that obtained at Bhátghar, and is remarkable for its great strength, its exceptionally good hydraulic quick-setting properties. It slakes very imperfectly and slowly and as a rule with scarcely any heat.

The lime was burnt in two kinds of kilns *i.e.*, in the ordinary above-ground intermittent kiln and in under-ground kilns. Holes varying from 8 to 10 feet diameter and 10 to 12 feet deep were excavated in hard *man* earth close to the steep face of a ravine near the river bank: a communication being made to the bottom of the kilns by a small tunnel from the face of the ravine. No lining was required, except at top for 2 feet, to pressure the edge. The time taken in burning is somewhat greater in this form of kiln than in the ordinary one, but the lime is invariably more uniformly burnt and with very small loss from over or under-burning. Another peculiarity in the lime-burning at Vir was the use of coke, coal, and refuse ashes obtained from the railway locomotives, mixed with charcoal. The proportion used was generally 3 maunds charcoal and 3 maunds coke and 3 maunds ashes to 100 c.ft. of kunker. Sometimes coal was used instead of the coke or ashes and the proportions had to be varied slightly according to the state of the kunker. The following method of treating this lime, for use in masonry works on small distributaries, has proved most useful and economical. The lime burnt in the usual way was ground *dry* and sifted through a fine sieve 1,600 meshes to the inch. The result was a fine dry powder resembling a light coloured cement.

To make mortar, the lime powder was thoroughly wetted, and then mixed by hand (phowras) with wet sand. Briquettes 2″ cube were made of mortar in proportion of 1 of sand to 1 of lime up to 5 to 1 and after 6 months were tested for compression. A briquette with the proportion of 1 to 1 resisted the full pressure that the machine could bring upon it; this amounted to 1,580 lbs. on the square inch, and specimen was as sound after as before the test. The specimen with 4 sand to 1 lime crushed at a little over 400 lbs. in the square inch, and it was decided to use the lime with this proportion of sand for all small works on distributaries. The lime is carried in bags to the different works and the mortar made at the site in the manner described above.

It has been found that mortar made in this way sets rather more slowly than that made in the ordinary way,

APPENDIX No. III.

Mortar tests.

Abstract from the register of Mortar tests, Bhâtghar Dam.

Date on which the mortar was made.			Date of test.			Age of specimen briquette.	Load at which the specimen crushed.	Remarks.
D.	*m.*	*y.*	*D.*	*m.*	*y.*	Months.	Lbs. per Sqr. Inch.	
2	1	1882	2	1	1888	72	1,127	
18	12	1882	17	6	1885	30	1,092	
18	12	1882	18	5	1885	29	966	
20	3	1883	18	5	1885	26	1,008	
1	4	1883	17	4	1885	25	999	
8	1	1884	7	3	1885	14	1,014	
23	3	1884	17	4	1885	13	1,080	
15	12	1884	14	3	1887	27	1,377	
18	4	1885	26	11	1886	19	961	
9	11	1885	14	4	1889	41	1,103	
12	11	1885	14	3	1887	16	1,050	
16	1	1886	3	2	1887	13	1,060	
25	11	1886	13	7	1889	32	1,026	
17	4	1886	11	6	1890	50	1,170	
23	3	1887	11	3	1890	36	864	
20	4	1887	21	7	1891	51	947	
30	3	1888	14	4	1889	12	871	
1	12	1888	13	11	1890	23	591	
13	6	1888	21	7	1891	37	597	
4	3	1889	11	3	1890	12	1,224	
6	3	1889	11	3	1890	12	756	
16	10	1889	15	4	1891	18	717	
17	5	1890	29	6	1891	13	1,009	3″ briquette.
19	5	1890	29	6	1891	13	897	,,
29	5	1890	29	6	1891	13	777	,,
9	5	1884	18	3	1885	10	965	2″ ,,
31	3	1885	18	2	1886	11	1,413	,,
10	3	1886	3	2	1887	11	840	,,
1	4	1883	5	12	1883	8	688	,,
22	10	1887	6	6	1888	7	577	,,
14	12	1888	19	7	1889	7	699	,,
22	6	1889	11	3	1890	9	777	,,
3	11	1890	29	6	1891	8	1,146	3″ ,,
1	5	1883	5	11	1883	6	436	2″ ,,
23	4	1884	18	11	1884	7	529	,,
1	4	1885	10	10	1885	6	632	,,
11	5	1886	26	11	1886	6	588	,,
2	12	1887	6	6	1888	6	420	,,
24	12	1888	19	7	1889	7	349	,,
3	5	1890	7	11	1890	6	528	,,
11	2	1890	5	7	1891	17	465	,,

Average results of Mortar tests.

Specimen 2″ cube used in the Bhâtghar Dam.

Age of Briquette.	Number of specimens tested.	Average crushing pressure.	
		Lbs. per Sqr. Inch.	
12 months and over	71	821	
11 to 12 months	16	838	
10 ,, 11 ,, ...	12	773	
9 ,, 10 ,, ...	11	777	
8 ,, 9 ,, ...	4	587	
7 ,, 8 ,, ...	7	638	
6 ,, 7 ,, ...	21	420	
5 ,, 6 ,, ...	22	610	
4 ,, 5 ,, ...	12	324	
3 ,, 4 ,, ...	24	398	
2 ,, 3 ,, ...	24	317	
1 ,, 2 ,, ...	40	263	

APPENDIX No. IV.

Statement shewing masonry and other works constructed on the Main Canal.

No.	Name of work.	Mileage of Canal.		Description.			Height of crown of arch above mean sea level.	Catchment area in square miles.
		Mile number.	Feet.	Number of Arches.	Span.	Rise.		
1	2	3		4			5	6
	Nira Canal.							
	Scouring sluice	...	25	...	...	...	...	...
	Overbridge No. 1	...	55	3	15	...	...	...
	1st Class Chauki at Virwadi.	...	...	...	..	...	...	...
	Culvert No. 1	...	2,120	1	3½	1¾	1833·62	0·25
	Do. 1A	...	4,440	1	4	2	1833·30	0·25
	Aqueduct No. A	1	1,720	1	15	4	1833·05	1·32
	Do. 1	2	130	3	30	4½	1832·17	6·53
	Do. 2	2	3,230	1	8	1½	1831·63	0·33
	Do. 3	3	3,624	2	30	4½	1830·86	6·13
	Do. 4	4	3,840	5	30	4½	1830·00	32·66
	Culvert No. 2	4	4,948	1	12	2½	1829·31	0·55
	Do. 3	6	2,760	1	12	3	1829·32	0·87
	Do. 3A	6	4,360	1	4	2	1828·88	0·10
	Do. 4	7	210	1	12	3	1828·62	0·87
	Do. 4A	7	3,644	1	4½	2¼	1828·10	0·03
	Scouring sluice	7	4,335	...	...	...	...	...
	Culvert No. 4B	8	1,015	1	4	2	1827·44	0·12
	Aqueduct No. 5.	8	3,825	2	25	3½	1826·84	2·00
	Railway Bridge, S. M.							
	Overbridge No. 2	8	4,338	1	30	...	...	...
	Culvert No. 4C	9	125	1	3	1½	1826·53	·35
	2nd Class Chauki at Pimpra.	...	...	...	...	...	...	...
	Distributary No. 14... ...	9	1,060	...	...	...	...	...
	Foot bridge at Pimpra ...	9	1,830	...	...	...	...	...
	Distributary No. 1 and 1A ...	9	2,330	...	...	...	...	...
	Culvert No. 5	9	3,822	...	...	...	1825·73	·83
	Distributary No. 1B... ...	10	1,100	...	...	...	...	...
	Aqueduct No. 6	10	1,820	4	30	4½	1825·12	19·98
	Distributary No. II	10	3,460	...	...	...	...	...
	Overbridge No. 3	10	4,671	1	25	...	...	...
	Masonry wall with sluice gate...	11	408	...	...	...	...	...
	Culvert No. 5A	11	600	2	15	4	1824·69	0·986
	Distributary No. III ...	11	2,455	...	...	...	...	...
	Culvert No. 5B	11	3,452	1	5	1½	1824·31	0·30
	Do. 5C	12	1,475	1	10	2¾	1824·17	0·27
	Overbridge No. 3A	12	3,470	1	21½	...	...	...
	Super-passage No. A ...	12	4,566	2	16	2½	1833·03	2·00
	Culvert No. 5D	13	2,900	1	5	2½	1823·14	0·168
	Do. 5E	13	4,550	1	10	3	1822·98	0·16
	Overbridge No. 4	14	1,980	1	35	...	...	...
	Distributary No. 4	14	2,740	...	...	...	...	...
	Do. No. 4A ...	15	12	...	...	...	...	...
	Culvert No. 5F	15	560	1	4	1½	1822·40	0·33
	Scouring sluice	15	1,320	...	...	...	...	...
	Distributary No. V	15	3,975	...	...	...	...	...
	Culvert No. 6	16	3,148	1	25	3½	1821·65	1·33
	Do. No. 6A	16	4,860	1	8	4	1821·50	0·373
	Distributary No. 5A... ...	17	1,010	...	...	...	...	...
	Culvert No. 6B	17	2,415	1	8	4	1821·23	0·217
	Distributary No. VI ...	17	5,065	...	...	...	...	...
	Culvert No. 7	18	4,488	1	10	1½	1820·45	0·33
	Overbridge No. 5	18	4,620	2	25	...	...	...
	Culvert No. 8	19	1,930	1	25	3½	1820·20	1·125
	Distributary No. 6A... } Do. No. 6B... }	19	2,840	...	...	...	...	...
	Aqueduct No. 8	19	4,080	4	30	4½	1819·60	7·40

No.	Name of work.	Mileage of Canal.		Description.			Height of crown of arch above mean sea level.	Catchment area in square miles.
		Mile number.	Feet.	Number of Arches.	Feet.	Rise.		
1	2	3		4			5	6
	Distributary No. VII ...	20	162	...	...	...	...	...
	Overbridge No. 5A ...	20	2,476	2	21	...	...	...
	Super-passage No. B ...	21	22	2	13	2½	1828·55	3·65
	Distributary No. VIII. ...	21	3,892	...	...	...	...	...
	Culvert No. 9	22	2,354	1	12	2½	1817·88	0·109
	Do. No. 9A	22	4,990	1	10	3	1817·57	0·314
	Distributary No. IX... ...	23	985	...	...	...	...	...
	Culvert No. 9B	23	2,542	1	4	1½	...	0·189
	Scouring sluice	23	2,691	...	...	...	...	...
	Overbridge No. 6	24	2,706	1	30	...	...	...
	2nd Class Chauki, Wadgaon .	...	...	...	...	...	...	...
	Distributary No. X	24	4,060	...	...	...	...	...
	Do. No. XI ...	24	4,060	...	...	...	...	...
	Aqueduct No. 10	25	884	8	30	4½	1815·88	40·36
	Super-passage No. 1 ...	26	706	2	16	2½	1824·24	1·11
	Overbridge No. 6B	26	1,536	2	20½	...	...	...
	Distributary No. XII ...	26	1,688	...	...	...	...	...
	Do. No. XIIA ...	...	...	...	...	...	...	...
	Super-passage No. 2 ...	27	1,402	2	16	2½	1822·92	6·5
	Distributary No. XIII ...	27	2,690	...	...	...	...	...
	Super-passage No. 3 ...	28	739	2	16	2½	1820·64	1·11
	Distributary No. XIV ...	28	1,430	...	...	...	...	...
	Overbridge No. 6C	28	3,685	1	26	...	...	...
	Super-passage No. 4 ...	29	1,530	2	16	2½	1820·11	1·46
	Distributary No. XV ...	29	2,916	...	...	...	...	...
	Overbridge No. 6A	29	4,500	1	18	...	...	...
	Distributary No. XVI ...	31	93	...	...	...	...	...
	Aqueduct No. 11	31	1,500	3	30	4½	1806·70	9·67
	Culvert No. 10	31	4,756	1	12	1½	1806·03	0·66
	Scouring sluice	31	5,101	...	...	...	...	...
	Stop-gate	32	108	...	...	...	...	...
	Distributary No. XVII ...	32	1,680	...	...	...	...	...
	Do. No. XVIII ..	33	830	...	...	....	...	...
	Do. No. 18A ...	33	4,450	...	...	...	...	...
	Culvert No. 11	34	1,520	1	20	3	1802·95	1·09
	Distributary No. XIX ...	34	3,450	...	...	...	...	...
	Overbridge No. 6D ...	34	3,700	1	30	...	...	...
	Foot bridge, at Pandára ...	34	4,718	1	21	...	...	...
	Overbridge No. 7	35	25	1	20	...	...	...
	Culvert No. 12	35	810	1	20	3	1801·35	1·09
	Super-passage No. 5 ...	35	2,257	Passages 2	15	2½	1809·71	5·41
	Overbridge No. 7A	35	3,870	2	19½	...	...	...
	Distributary No. XX ...	35	4,212	...	...	...	...	...
	Super-passage No. 6 ...	36	171	Passages 2	15	2½	1807·93	1·00
	2nd Class Chauki, at Pandára.	...	...	...	...	...	...	...
	Distributary No. XXI ...	36	2,520	...	...	...	...	...
	Culvert No. 12A	36	4,202	1	12	2	1800·28	0·80
	Do. No. 12B	37	4,210	1	6	1	1799·07	0·23
	Distributary No. XXII ...	37	4,680	...	...	...	...	...
	Canal Stop-gate	38	110	...	...	...	...	...
	Overbridge No. 7B	38	538	1	16	...	...	...
	Distributary No. 21A ...	38	4,902	...	...	...	...	...
	Super-passage No. 8A ...	38	5,127	2	12	2	1808·99	3·50
	Culvert No. 12C	39	110	1	10	2½	1796·08	0·46
	Overbridge No. 9	39	2,230	1	21½	...	...	...
	Distributary No. 22A ...	39	2,520	...	...	...	...	...
	Culvert No. 13	39	4,593	1	12	1¾	1795·19	0·80
	Distributary No. XXIII ...	40	2,620	...	...	...	...	...
	Culvert No. 14	40	4,745	1	12	1¾	1794·14	0·80
	Distributary No. XXIV ...	41	1,990	...	...	...	...	...
	Do. No. XXV ...	42	4,363	...	...	...	...	...
	Culvert No. 14A	42	4,872	1	5	1	1791·62	0·08
	Overbridge No. 9A	43	84	2	16	...	...	...

No.	Name of work.	Mileage of Canal.		Description.			Height of crown of arch above mean sea level.	Catchment area in square miles.
		Mile number.	Feet.	Number of Arches.	Span.	Rise.		
1	2	3		4			5	6
	Culvert No. 15	43	4,332	1	12	1¾	1790·98	0·80
	Aqueduct No. 13	44	1,030	3	30	4½	1790·39	12·43
	Distributary No. XXVI ...	44	4,035	...	...	...	...	...
	Overbridge No. 9B ..	44	4,229	2	16	...	...	...
	Aqueduct No. 14	45	2,356	13	30	4½	1789·10	440·00
	Overbridge No. 10	45	4,030	1	27	...	...	...
	Scouring sluice	45	4,352	...	...	...	...	...
	Culvert No. 16	46	1,238	1	7	1¾	1788·00	0·20
	Aqueduct No. 15	47	260	3	30	4½	1787·73	6·30
	Distributary No. XXVII ...	47	4,475	...	...	...	...	...
	1st Class Chauki, at Bárámati.	...	...	...	...	...	...	...
	Culvert No. 16A	48	156	1	4	1	1787·12	0·20
	Do. No 17	48	1,339	1	7	1¾	286·97	0·20
	Overbridge No. 11	48	2,555	1	34	...	...	...
	Distributary No. XXVIII ...	48	3,196	...	...	...	...	...
	Culvert No. 18	48	5,121	1	7	1¾	1786·52	0·375
	Distributary No. 28B ...	49	2,483	...	...	...	...	...
	Culvert No. 19	49	4,595	1	12	1¾	1786·00	0·70
	Scouring sluice	49	5,220	...	...	...	...	...
	Aqueduct No. 16	50	1,245	4	30	4½	1785·35	17·33
	Culvert No. 20	50	2,608	1	8	2½	1785·24	0·23
	Distributary No. 28A ...	50	4,054	...	...	...	...	...
	Culvert No. 21A	51	2,768	1	12	2½	1784·51	0·56
	Overbridge No. 13	51	3,098	1	30	...	...	...
	Distributary No. XXIX ...	51	3,977	...	...	...	...	...
	Culvert No. 22	52	1,072	1	4	1	...	...
	Do. No. 22A	52	2,621	1	4	1	1783·62	0·08
	Distributary No. XXX ...	52	3,337	...	...	...	...	...
	Overbridge No. 14	52	4,077	1	10	...	...	...
	Culvert No. 23	52	4,829	1	4	1½	...	0·08
	Do. No. 24	53	2,707	1	10	3	...	...
	Distributary No. XXXI ...	54	3,370	...	...	...	...	...
	Culvert No. 25	55	646	1	4	1	1781·32	0·08
	Do. 26	55	4,166	1	4	1	1780·88	...
	Do. 27	56	2,529	1	12	2	1780·44	0·68
	Do. 28	56	3,744	1	20	3	1780·35	1·64
	Distributary No. XXXII ...	57	3,394	...	...	...	...	...
	Culvert No. 30	58	3,027	1	20	3	1779·03	1·64
	Overbridge No. 14B... ...	58	5,011	1	30	...	...	...
	Culvert No. 31	59	1,130	1	7	3½	1778·63	0·35
	Distributary No. XXXIII ...	60	3,303	...	...	...	...	...
	Overbridge No. 14A ...	60	3,356	1	14	...	...	...
	Culvert No. 32	61	924	1	12	2	1775·54	0·68
	Distributary No. XXXIV ...	61	2,459	...	...	...	...	...
	Culvert No. 33	61	3,127	1	4	1	1775·30	0·08
	Do. 34	61	4,465	1	10	3	1774·86	0·56
	Do. 35	62	35	1	4	1	1773·80	0·08
	Do. 36	62	669	1	4	1	1774·55	0·08
	Distributary No. XXXV ...	62	3,844	...	...	...	...	...
	Culvert No. 37	63	1,320	1	4	1	1774·03	0·08
	Overbridge No. 15	63	1,725	1	29½	...	...	...
	Distributary No. XXXVI ...	63	4,000	...	...	...	...	...
	Culvert No. 38	63	5,136	1	4	1	1772·85	0·08
	Distributary No. XXXVII...	64	960	...	...	...	...	...
	2nd Class Chauki, at Sansar...	...	...	...	...	...	...	...
	Overbridge No. 16	64	1,430	1	29¼	...	...	...
	Aqueduct No. 17	65	2,640	3	25	3¾	1771·41	9·75
	Distributary No. XXXVIII...	65	5,128	...	...	...	...	...
	Aqueduct No. 18	66	2,275	2	30	4½	1770·22	11·53
	Culvert No. 40	67	94	1	8	2	1769·85	0·38
	Overbridge No. 18	67	2,910	1	28	...	...	...
	Distributary No. XXXIX ...	67	4,737	...	...	...	...	...
	Culvert No 41	68	365	1	4	2	1768·76	Area 0·68

No.	Name of work.	Mileage of Canal.		Description.			Height of crown of arch above mean sea level.	Catchment area in square miles.
		Mile number.	Feet.	Number of Arches.	Span.	Rise.		
1	2	3		4			5	6
	Distributary No. XL ...	68	2,640	...	...	...	...	...
	Culvert No. 41A	69	1,031	1	6	2	1768·65	0·42
	Distributary No. XLI ...	69	2,629	...	...	...	...	...
	Aqueduct No. 19	69	4,435	2	30	4½	1767·94	9·18
	Distributary No. XLII ...	70	3,222	...	...	...	...	...
	Culvert No. 42	71	720	1	10	2	1767·01	0·56
	Distributary XLIIA ...	71	1,045	...	...	...	...	...
	Do. XLIII	71	4,145	...	...	...	...	...
	Overbridge No. 19	72	660	1	22	...	...	...
	Culvert No. 43	72	2,430	1	4	1½	1765·45	0·15
	Distributary No. XLIV ...	72	4,300	...	...	...	...	...
	Culvert No. 43A	73	1,370	1	13	2½	1765·00	0·95
	Distributary No. XLV ...	74	225	...	...	...	...	...
	Do. XLVI ...	74	1,570	...	...	...	...	...
	Culvert No. 44	75	1,932	1	20	3	1703·42	2·00
	Do. No. 45	76	450	1	6	1	1762·93	0·21
	Distributary No. XLVII ...	...	...	...	...	...	...	...
	Do. No. XLVIII ...	76	3,454	...	...	...	...	...
	Overbridge No. 19A ...	76	3,510	1	16	...	...	...
	2nd Chauki, at Haturna ...	...	...	...	...	...	...	...
	Culvert No. 46	77	2,700	1	26	4⅙	1761·20	0·343
	Distributary No. XLIX ...	...	...	...	...	...	...	...
	Culvert No. 46A	78	1,500	1	6	1	1760·75	0·08
	Overbridge No. 20	78	2,890	1	12	...	...	...
	Distributary No. L	78	3,800	...	...	...	...	...
	Culvert No. 47	79	1,595	1	18	3	1759·33	1·5
	Distributary No. LI... ...	79	3,333	...	...	...	...	...
	Culvert No. 48	79	4,025	1	25	4¼	1758·95	2·8
	Distributary LII	...	...	...	...	...	...	...
	Culvert No. 49	80	1,780	2	15	3	1758·58	4·5
	Do. No. 50	80	3,040	1	12	2½	1758·06	0·36
	Do. No. 51	80	3,460	1	4	1½	1757·88	0·24
	Overbridge No. 22	81	261	1	15	...	...	...
	Distributary No. LIII ...	82	220	...	...	...	...	...
	Culvert No. 52	82	3,690	1	12	6	1755·92	1·00
	Do. No. 53	83	3,450	2	18	3	1755·30	0·93
	Distributary No. LIV ...	85	304	...	...	...	...	...
	Culvert No. 54	85	4,425	1	10	2½	1753·35	0·37
	Do. No. 55	86	2,059	1	14	10	1753·08	0·95
	Overbridge No. 23	87	878	1	12	...	...	...
	Distributary No. LV ...	87	4,517	...	...	...	...	...
	Culvert No. 56	88	2,973	1	20	12	1749·99	1·14
	Do. No. 57	89	2,670	1	12	3	1749·36	0·31
	Do. No. 58	89	4,650	1	15	3	1749·12	0 31
	Distributary No. LVII ...	89	4,775	...	...	...	...	...
	Overbridge No. 24	90	439	1	13	...	...	...
	Distributary No. LVIII ...	90	3,482	...	...	...	...	...
	Culvert No. 59	91	1,445	1	8	4	1746·64	0·33
	Aqueduct No. 22	91	4,433	3	30	4½	1745·93	14·00
	Culvert No. 60	92	3,390	1	20	11½	1745·40	1·34
	2nd Class Chauki at Nimbgaon...	...	...	...	...	...	...	...
	Culvert No. 61	93	1,290	1	19	4½	1744·97	0·7
	Overbridge No. 25	93	4,630	1	16	...	...	...
	Culvert No. 62	94	560	1	8	2	1744·37	0·24
	Do. No. 63	94	4,221	1	10	5	1743·86	0·48
	Do. No. 64	95	1,702	1	8	1½	1743·43	0·14
	Distributary LIX	95	3,223	...	...	...	...	...
	Culvert No. 65	96	503	1	11	6½	1741·13	0·53
	Do. No. 66	97	1,311	1	10	2	1740·09	0·31
	Overbridge No. 28	97	3,823	1	12	...	...	...
	Culvert No. 67	98	1,761	1	14	2¾	1739·22	0·83
	Do. No. 68	99	1,954	1	12	2½	1738·44	1·04

APPENDIX No. V.

Statement giving information regarding Distributaries.

Distributary No.	Discharge of Main Canal.	Mileage of Main Canal.		Length of Distributaries including Branches.		Description of Regulator.	Estimated full discharge at head, cubic ft.	Gross area commanded.	Net irrigable area commanded.	Total cost.	Cost per acre commanded.
1	2	3		4		5	6	7	8	9	10
		M.	ft.	M.	ft.			Acres.	Acres.	Rs.	Rs.
1 C		9	1,060	No channel.		6″ valve ...	Pipe outlet		60	148	2·46
1 & 1 A	456	9	2,330	2	2,840	12″ ,, ...	6		1,178	1,350	1·15
1 B		10	1,100	No channel.		6″ ,, ..	Pipe outlet	3,297	50	134	2·68
2		10	3,460	...	4,200	9″ ,, ...	2		260	507	1·94
3	444	11	2,455	1	2,020	12″ sqr. gate.	5·30		1,276	515	0·40
4		14	2,740	1	4,720	9″ valve ...	3·60	2,509	758	638	0·84
5		15	3,975	2	60	12″ gate ...	6·95		1,417	900	0·63
6		17	5,065	2	1,700	18″ ,, ...	16·00	4,056	3,369	1,896	0·56
with 2 branches	443										
7		20	162	1	720	9″ valve ...	32·00	3,371	627	742	1·18
8		21	3,892	3	1,460	18″ gate ...	12·00		2,400	1,861	0·77
9	435	23	985	1	1,220	9″ valve ...	2·00		410	477	1·16
10		24	4,060	1	2,220	12″ gate ..	3·50	2,619	720	499	0·69
11	429	24	4,060	2	1,440		6·00		1,229	1,028	0·83
12		26	1,688	3	160	12″ ,, ...	5·00	1,371	1,084	2,640	2·48
13	423	27	2,690	4	...	18″ ,, ...	14·50	3,188	2,845	3,064	1·07
14		28	1,430	...	3,500	9″ valve ...	2·00		423	1,489	3·52
15		29	2,916	5	3,900	18″ gate ...	12·90	7,299	2,540	5,933	2·33
16	417	31	93	4	3,380	18″ ,, ...	12·30		2,447	4,589	1·87
17		32	1,680	2	190	12″ valve ...	5·25	...	1,023	1,832	1·79
18		33	830	9	1,843	2′ sqr. gate.	33·50	12,680	9,703	6,630	0·68
18 A	406	33	4,450	...	...	9″ valve ...	..	...	...	215	...
19		34	3,450	...	...	15″ gate ...	...	...	641	305	0·75
										176	
20	404	35	4,212	...	100	.....	...	...	170	176	1·03
21		36	2,520	...	1,600	9″ valve ...	2·00	10,036	380	349	0·91
21 A		38	4,902	..	...	.....	Pipe outlet		160	287	1·80
22	375	37	4,680	5	3,408	3′ gate ...	32·80	...	7,800	9,919	1·27
22 A	361	39	2,520	....	100	6″ valve ...	Pipe outlet	...	110	141	1·28
23		40	2,620	...	726	6″ ,, ...	...		240	223	0·93
24		41	1,990	7	158	3′×2′ gate .	47·00	18,041	14,618	12,876	0·88
25	330	42	4,363	...	200	9″ valve ..	2·00		750	252	0·34
26		44	4,035	...	900	10″ ,, ...	3·00		561	327	0·58
27		47	4,475	...	700	6″ ,, ...	1·50	1,981	127	187	1·47
28		48	3,196	...	400	10″ ,, ...	3·00		583	499	0·85
28 A	308	50	4,054	...	...	6″ ,, ...	...	80	80	129	1·61
28 B		49	2,483	No channel.		6″ ,, ...	Pipe outlet	100	100	143	1·43
29		51	3,977	1	3,270	12″ ,, ...	8·00	2,198	1,608	989	0·61
30		52	3,337	4	905	3′ gate ...	35·00	6,617	6,000	4,407	0·73
31		54	3,370	...	5,230	12″ valve ...	7·80	1,914	1,191	1,172	0·98
32	292	57	3,394	...	100	9″ ,, ..	...		388	250	0·64
33		60	3,303	2	2,320	3′ gate ...	11·00		2,157	2,828	1·31
34		61	2,489	No channel.		6″ valve ...	Pipe outlet	3,182	162	141	0·87
35		62	3,844	Do.		9″ ,, ...	...		418	233	0·55
36		63	4,000	4	3,952	.....	45·30		9,694	7,158	0·74
37		64	960	...	1,000	9″ valve ...	3·70	12,068	416	341	0·82
38		65	5,128	No channel.		6″ ,, ...	Pipe.		147	150	1·02
39		67	4,737	...	3,896	12″ ,, ...	5·80	1,520	1,238	816	0·65
40	277	68	2,640	...	2,700	9″ ,, ...	2·80		343	442	1·28
41		69	2,629	No channel.		4″ ,, ...	Pipe.	937	98	89	0·90
42		70	3,222	Do.		9″ ,, ...	Do.		405	215	0·53
42 A		71	1,045	1	610	.....	7·00	1,619	1,429	1,044	0·73
43		71	4,145	4	2,123	2′ gate ...	28·62		5,796	5,052	0·87
44	264	72	4,300	...	...	6″ valve ...	Outlet.	6,944	120	158	1·31
45		74	225	...	...	9″ ,, ...	Do.		281	262	0·93
46	248	74	1,570	5	100	3′×2′ gate .	40·50	11,696	9,835	6,008	0·61
48		76	3,454	1	3,195	3′×2′ ,,	12·00		2,374	1,858	0·78
50		78	3,800	...	4,512	10″ valve ..	5·00	3,871	801	773	0·96
51	234	79	3,333	...	...	.....	Pipe outlet		195	157	0·80
53		82	220	1	720	15″ gate ...	10·00	2,749	2,070	1,165	0·56
54		85	304	4	4,748	3′×2′ gate .	50·00	10,501	9,071	5,849	0·64
55	212	87	4,517	1	5,275	2′ gate ..	16·00	3,256	2,792	1,776	0·63
57		89	4,775	8	560	3′ sqr. gate.	54·00	21,471	15,931	19,599	1·23
58	184	90	3,482	1	1,140	10″ valve .	8·50		792	2,785	3·51
59	176	95	3,223	23	1,986	Gate ...	114·00	57,242	47,971	57,863	1·20
			Add for	pipe	outlets.	.....	25·00	...	...	...	...
				132	2,447		762·12	218,413	183,862	1,86,650	1·01
60	Not constructed.			7	334		...	15,803	12,946	19,503	1·50
61				12	2,781		....	40,231	30,862	46,890	1·52
	Total ...	...	...	152	282		762·12	274,447	227,670	2,53,043	1·11

APPENDIX No. VI.

Note on designing the section of the Bhátghar Dam.

1. The instructions given for the design of the profile of the dam were that the top width should not be less than 10 feet, that the intensity of pressure due to the vertical component only of the resultant should not exceed 120 lbs. per square inch, and that the resultant pressure should in all cases fall within the middle third of the section.

M. Bouvier's pamphlet was known, and it was well understood that the actual intensity of pressure depended upon the resultant of the water pressure and the weight of materials in the dam, but in order to compare the results with existing masonry dams it was thought desirable to calculate the intensity of pressure in the way it had been calculated for existing dams.

It was also ordered that the intensity of pressure due to the resultant of the water pressure and the weight of the dam should be calculated by M. Bouvier's theory.

2. Before commencing the calculations the weight of the materials to be used was carefully ascertained.

Water was taken at 62·5 lbs. per cubic foot and the corresponding weights of the stone at the site and of mortar and concrete made from the materials at the site were determined by weighing a number of blocks of not less than half a cubic foot in size in water and in air and thence finding the weight per cubic foot.

The experiments showed that the weight of the mass of the dam would slightly exceed 60 lbs. per cubic foot and this weight was taken for calculation.

This is higher than usual, but the trap rock at Bhátghar is a very heavy rock and weighed on the average over 183 lbs. per cubic foot. Some specimens were as much as 190 lbs. but these were not included in the list from which the average weight was obtained.

The sand and gravel from the same rocks were heavy in proportion.

3. The profile and lines of resistance were determined graphically as follows; the method being similar to that commonly used for retaining walls.

A trial section, with the given top width, was assumed for the top 30 feet of the dam. See Figure 1.

The centre of gravity of the section was found, and a vertical line, representing the direction of W the resultant of the weight of the section, drawn through the centre of gravity. The point where this line cut the base was a point on the line of resistance when the reservoir was empty.

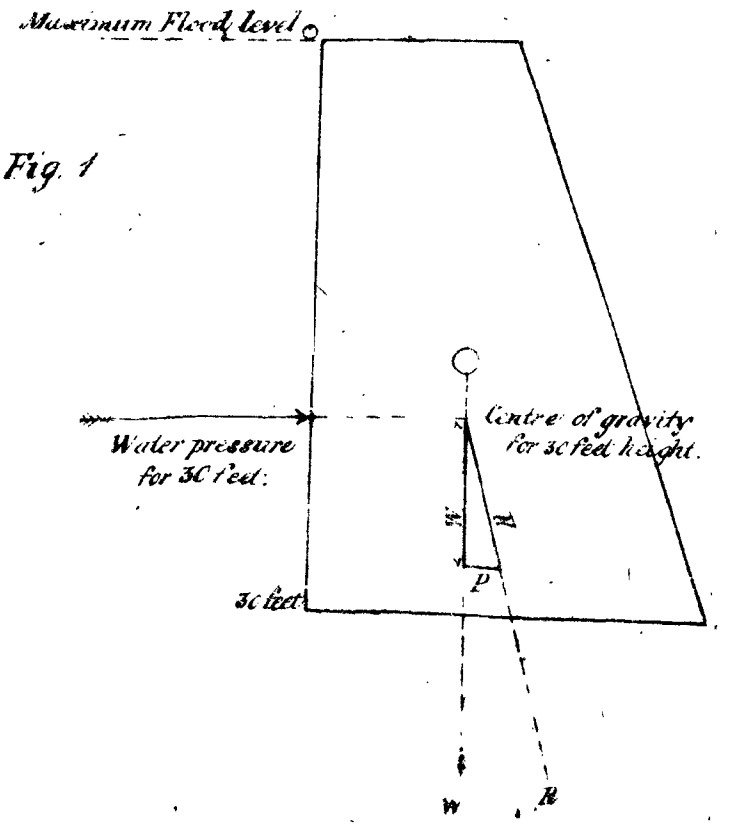


Fig. 1

The maximum flood level was taken as the height of the water

The resultant of the water pressure, P, a force known in amount and direction, was drawn and produced to meet the line of the weight W. From the point of intersection a length was marked off along W proportional to the weight of the dam; and from the bottom of the length so marked off a line was set out parallel and proportional to P. The line joining the ends of these lengths and completing the triangle represented R, the resultant of the weight and water pressure, in amount and directions and the point where R cut the base was a point on the line of resistance when the reservoir was full.

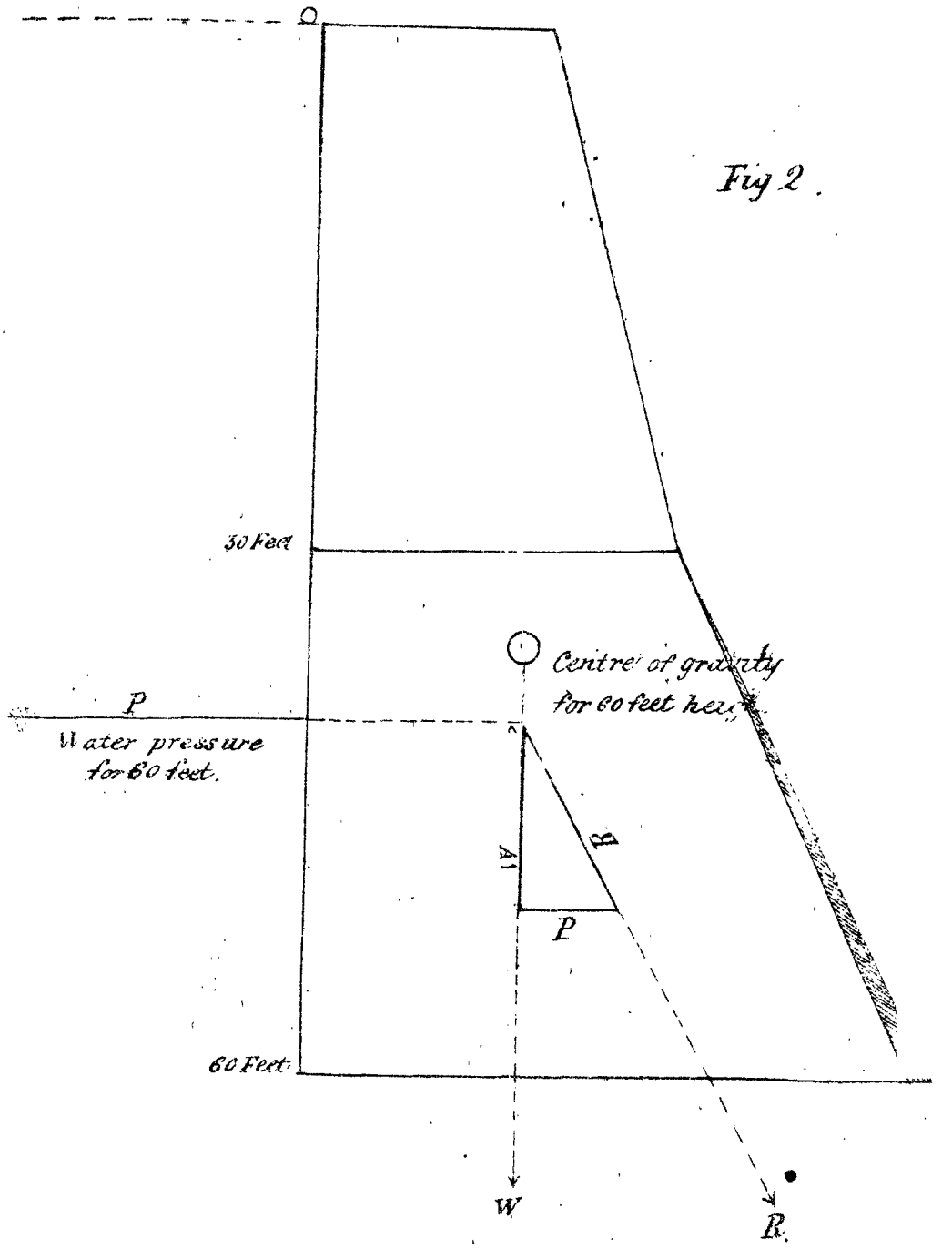


Fig 2.

The first trial step being completed another 30 feet length was added, the down-stream batter being increased. See Figure 2.

The centre of gravity for the whole 60 feet height was found; the resultant water pressure for the whole 60 feet depth was drawn, and the amount and direction of R, and the points where W and R cut the base, *i.e.*, where the lines of resistance cut the base, determined in the way just described.

If the point where R cut the base fell too far within the middle third, then the batter of the lower 30 feet was altered; the upper part being left undisturbed. In other words, the slice shown shaded in fig. 2 was cut off.

The size of the slice to be cut off is very small compared with the whole mass of the dam, and the position of the centre of gravity will not be appreciably altered by its removal, and also the amount and direction of R will be but slightly altered, the new position being readily found, if desired, by shortening the side W of the triangle of forces by an amount proportional to the weight of the slice. Hence the breadth of the base of the shaded slice may be taken, so that R fall just within the middle third of the reduced base of the dam.

Vice versa if R fall at first without the middle third, a slice may be added. Two other lengths were added to the bottom of the profile in a similar way and a rough profile of the dam obtained for the full height required.

5. The intensity of pressure was calculatad by the usual formula, one form of which is.

The intensity of pressure$=p=\frac{R}{A}\left(1+\frac{6v}{x}\right)$.

Where a is the area of the base.

x the width of the base.

v the distance of the line of resistance from the centre of the base.

As stated above the vertical component only of R was used for one set of calculations and for the other M. Bouvier's theory was used.

6. On examining the section thus rapidly obtained it was seen that if the line of resistance, when the reservoir was empty, were brought nearer the edge and fell slightly without the middle third, the pressure on the up-stream toe would not be unduly high.

Mr. Whiting therefore determined to make this alteration, and by adding weight on the top of the dam above the water level in the cheaper form of heavy stone boulders between retaining walls, to save expensive masonry in the lower portion of the section.

This alteration was made and a curve drawn to correspond to the down-stream profile and the lines of resistance and pressures were then calculated in the way described for every ten feet in height.

7. This method of calculation is simple and each calculation acts as a check on the ones above and below, any error being shown as a break in the regularity of the curves of the lines of resistance. The position of the centre of gravity and the weight of the whole dam or of a portion can readily be checked in various ways, for instance, by finding the centre of gravity and weight of the whole area A B C D and the alteration made by deducting the segment B E C.

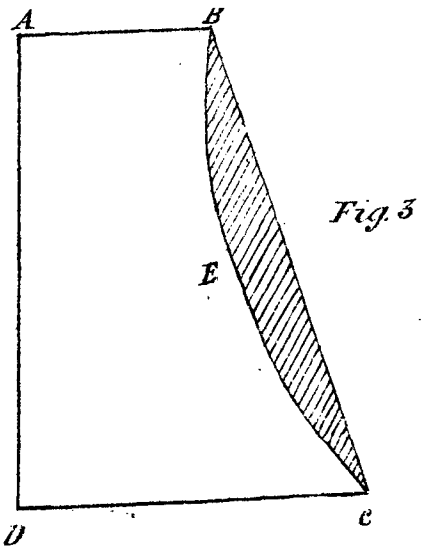


Fig. 3

8. An absolute check can be readily kept on all the calculations and freedom from error assured.

The maximum intensity of pressure on the down-stream toe was calculated by M. Bouvier's theory, and the method is very convenient and sufficiently accurate for the lower parts of high dams, but must be used with caution as there are cases for which it is quite unsuitable.

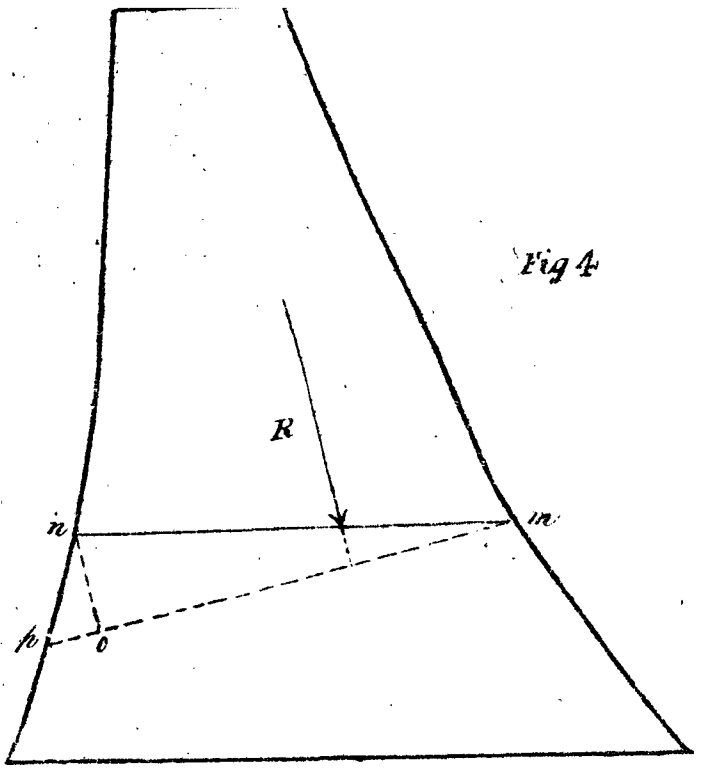


Fig 4

M. Bouvier states that if $n\ m$ be a horizontal joint and $m\ p$ be drawn at right angles to the resultant force R (*See* Figure 4),

"it is useless to take into account the weight of the masonry in the triangle $n\ m\ p$, and the "pressure of water exerted on $n\ p$, which will have no effect on the point m."

Now this assumption does not take into consideration the shape of the profile of the dam, and for battered profiles the weight of, and the water pressure on, the masonry below $n\ m$, *as far as a line through* m *and at rightangles to the neutral axis* of the profile, does affect the point m. This may be tested by trial.

Again M. Bouvier reasons as follows:—

"The force R can be decomposed from n to m into parellel forces, the transmission of "which to the joint $m\ p$ can only take place from m to o, and consequently we can only admit "the length $m\ o$ into the calculation as the real length of the joint required for equilibrium "between the forces, by equivalent normal re-action."

This reasoning of M. Bouvier is clearly wrong for rough bodies such as stones bonded together and cemented by mortar. The fallacy is at once evident if it be considered how the water pressure is resisted. There is no plane normal to the water pressure and no "*equivalent normal re-action*", but the whole of the water pressure is resisted at the bottom of the dam along a plane parallel to the water pressure.

Again it is well known that footings at the base of a heavy wall distribute the weight, and that the pressure on the foundation is not confined to a portion, of the width of the base of the wall.

Hence M. Bouvier's theory cannot be accepted as correct, and for cases where the resultant is very oblique to the plane of the joint the error is very serious.

Such cases occur, for instance, at the top of a weir over which a considerable height of water flows with a free over-fall, and if the formula be applied to the special case of a weir with falling gates fixed on the top, then the resultant R on the top strip of weir is parallel to the top of the weir, see figure 5, and the whole resultant passes through the point *m*, so that according to the formula the pressure at *m* must be infinite and the materials crush.

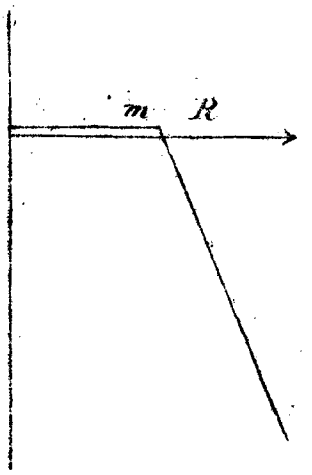


Fig 5

10. If true results of the intensity of pressure be required, it is necessary to consider the shape of the profile *a b d c* (see figurte 6) and to calculate the resulant of all the forces upon a plane *c d* at rightangles to the neutral axis *e f*, and to find by usual formula (see paragraph 5) the maximum intensity of pressure due to the amount and position of the resultant.

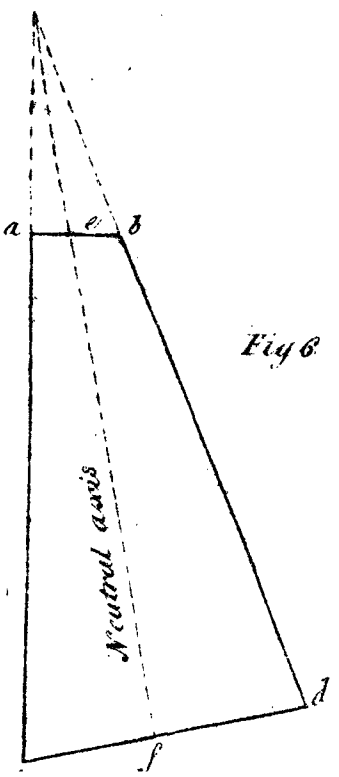


Fig 6

This cannot be conveniently done until the profile has been finally determined, and M. Bouvier's method which is right in taking the whole resultant into account, and also right in making the intensity of pressure at a point in the down-stream face greater than that due to the forces through a horizontal plane at the point, gives results sufficiently accurate for dams, but cannot be trusted for the upper parts of weirs or similar cases where the resultant is very oblique to the plane of the joint.

When using for such cases the formula quoted in paragraph 5, it must be remembered that the formula is based on the assumption that the resultant fall within the middle third of the section, and if the resultant fall without the middle third the case must be specially considered.

A. HILL, F.C.H.,
Executive Engineer, P. W. D.

Tánsa Dam, 12th October 1890.

APPENDIX VII.

GOVERNMENT OF BOMBAY. PUBLIC WORKS DEPARTMENT.

Papers relating to Mr. E. K. Reinold's Sluice Gate and Mr. J. E. Whiting's Steel Needles.

MEMORANDUM.

The problem, how to provide moveable instead of fixed waste weirs for storage reservoirs, is one that has engaged the attention of Engineers of the Irrigation Department in this Presidency for some years. In designing a dam for a storage reservoir, the section of the dam is calculated with reference to the maximum head of water in the reservoir, a waste weir being provided to pass off floods with a certain maximum depth of flow over the crest, this depth being calculated according to the special conditions of each site. It thus happens that, in the case of an open or fixed weir, a certain portion of the head, on which the dam section is calculated, corresponding to the depth of flow over the weir, is wasted as regards the storage. The problem, therefore, is to devise some means of securing the storage due to the depth of maximum flood discharge above the crest of the weir, without interfering with its discharging capacity, and at the same time without involving any possibility of the water in the reservoir being raised above the height for which the dam section was calculated.

2. The special difficulty attending the problem in this Presidency is that, at the close of the monsoon, when a reservoir is full, storms may occur of such intensity as to produce a heavy, if not a maximum, flood. In the case, therefore, of a moveable weir, the arrangement must be such that, in the event of a sudden flood, all obstructions on the weir shall be removed to provide for the required discharge. Up to the present, the principal, practical attempt that has been made to store water above weir crest level is at Lake Fife, the storage for the Mutha Canals. A certain length of the waste weir has always been left low, and from the beginning this portion was closed after the monsoon by an earthen bank. This bank was subsequently extended over the whole weir, so as to store about 2 feet above the finished crest level. This arrangement was defective and inefficient owing to the risk of the temporary bank being washed away, and the extra storage being lost, possibly beyond hope of future replenishment in that season, and in 1884, Government sanctioned a design for raising the water to a height of 4 feet above crest level, by means of planks fixed in iron standards, which were removeable, and were intended to be placed in position, when the monsoon floods had subsided. This could only be termed an improvement on the earthen bank, for it was attended with nearly the same risk of failure in the event of a sudden heavy flood. To reduce this risk, 12 "fixed" gates, each 10 feet × 6 feet were erected in 1887, so as to pass off small floods after the planks had been fixed and the reservoir filled. This arrangement has been only partially successful, the maximum depth of extra storage secured has been 3·75 feet only, and it being dependent upon exigencies, has been as low as 2·99 feet (1890). As each extra foot of storage at this level represents a volume of over 150 millions of cubic feet, the great importance of a more efficient means of securing the end can be appreciated, and experience conclusively proves that, to ensure the full additional storage, the method must be automatic, both as to opening and closing, or in the event of an automatic action being impracticable, that the means adopted for closing the weir should be easily and quickly worked.

3. The first engineer in this Presidency to offer a solution of the problem was Mr. J. E. Whiting, M.Inst. C. E., who, when Executive Engineer, Nira Canal, designed a self-opening falling gate for the storage of water on the waste weir of the Bhátghar Reservoir. The gate worked as a flap on a hinge in the crest of the weir, and was kept closed by means of a counter-weight attached by chains to the two top corners of the gate. The counter-weight was suspended in a water-tight chamber built in the body of the weir, and water was admitted to it when the level in the reservoir rose to Highest Flood Level. When the counter-weight was submerged, the loss of weight was sufficient to release the gate, which was pushed open by the water pressure against it. Forty-five of these gates, each 10 feet wide by 8 feet high, were proposed for the waste weir. The principal objection to this form of sluice gate was that it would not close until the water in the reservoir had fallen to within 2 feet of the sill, thereby losing storage to the extent of 6 feet. In 1889, Mr. E. K. Reinold, Executive Engineer, invented another form of sluice gate for the purpose, a full description of which is given in the following papers. The working model was so favourably reported on by the Engineers appointed by Government to inspect it, that an experimental gate was ordered to be made of the dimentions required for the waste weir for the Bhátghar Reservoir, *viz.*, 10 feet wide and 8 feet high. The result of this experiment is set forth in the proceedings of the Committee appointed to report upon it, and shows that this form of gate appears to offer a satisfactory solution to the problem of moveable waste weirs, in that, it secures the full storage in a reservoir up to the maximum flood level, and allows all surplus water to be discharged with practically no risk of loss of the extra storage above weir crest.

4. In revising the designs for the Bhátghar Reservoir in 1885, two waste weirs were proposed, one at the north and one at the south end of the dam. On the north weir, it was proposed to have 45 openings by means of piers and arches, each 10 feet span, to be closed by

self-opening falling gates, and on the south, 36 openings, which it was proposed to close after the monsoon floods had subsided, by means of steel needles designed and patented by Mr. Whiting, then Executive Engineer. Steel needles were also proposed in the case of the weir recently constructed at Gokák, to raise the storage to a height of 9 feet above the weir crest, when all danger of heavy floods had passed, a certain number of automatic gates being provided to pass off small floods that might occur after the full storage had been secured. At Bhátghar, nearly 500 needles were required, and at Gokák the length of weir to be closed was over 2,000 feet. Government, therefore, appointed a Committee, to experiment with the steel needles and report on their merits, as compared with teak needles, and on the advisability of adopting them for canal regulators or for other purposes. This Committee was also ordered to conduct the inquiry into the merits of Mr. Reinold's gate.

No. 1268 OF 1891.

FROM

THE CHIEF ENGINEER,
Central Division;

To

THE SECRETARY TO GOVERNMENT,
Public Works Department, Bombay.

Poona, 19th March 1891.

SIR,

With reference to para. 2 of Government Resolution No. 7 W. I.—94, dated 17th January 1891, and in continuation of this office No. 1086, dated 11th instant, I have the honour to forward herewith, for the information of Government, proceedings of the Committee met on 2nd and 4th March 1891 at Vir and at Poona Water Works for enquiring into, and reporting on, the merits of Mr. Reinold's Sluice Gate and Mr. Whiting's Steel Needles.

I have the honour to be,
Sir,
Your most obedient servant,
W. S. HOWARD, M.Inst.C.E.,
Chief Engineer, Central Division.

Proceedings of a Committee appointed by Government (Government Resolution No. 7 W. I.—94, dated 17th January 1891,) to enquire into, and report on, the merits of Mr. Reinold's Sluice Gate and Mr. Whiting's Steel Needles.

PRESIDENT:

W. S. Howard, Esq., M.Inst.C.E., Chief Engineer, C.D.

MEMBERS:

S. B. Doig, Esq., M.Inst.C.E., Executive Engineer, Ahmedabad,
W. H. LeQuesne, Esq., Executive Engineer, Níra Canal,
E. F. Dawson, Esq., Executive Engineer for Irrigation, Dhárwár.

The Committee met at Vir on the 2nd March, where an experimental automatic gate of Mr. Reinold's pattern had been erected.

2. A note by Mr. LeQuesne, explaining the action of the gate, is attached to this report; also a tracing* showing the site on which the gate has been erected.

*Not printed.

3. The invention consists of a gate on rollers combined with a special form of joint, which is water-tight, without sliding surface friction; when the gate, therefore, is in action, the resistance to be overcome, due to the water pressure, is rolling friction only. The inventor claims that this gate is applicable to any form of sluice, and can be worked by means of any suitable hoist, or it can be made to work automatically.

4. The Committee having made themselves acquainted with all the features of the design, proceeded to examine the experimental gate, the conditions under which it had been erected being then explained. These conditions are—

(1) that it should meet the requirements of the Bhátghar north waste weir, in that, the gate should be 10 feet wide by 8 feet high, and that the counter-weight, necessary for the automatic action, should be of the dimensions fixed by the size of the chambers already built in the weir;

(2) that the gate should be perfectly automatic, both as to opening and closing;

(3) that it should be practically water-tight.

5. Some defects that had occurred in the construction of the gate were then pointed out.

(1.) Owing to the lugs from which the gate is suspended being incorrectly placed with reference to the centre of gravity, the four wheels of the gate do not all press evenly on the runners, as it was designed they should do. When the gate is hanging freely with no water against it, the two upper wheels press against the runners, but the lower ones are clear, and the lower horizontal edge of the gate hangs slightly away from the frame. The gate, however, is brought to its bearings by the water pressure.

(2.) Owing to a defect in construction, one of the wheels is not in plane with the other three.

(3.) Owing probably to the soft character of the metal used, the lower horizontal rib of the gate bends slightly, when there is a full head of water against it.

6. The Committee are satisfied that these defects in no way affect the principle of the design, and that they prove how important it was to have an experiment on this scale. The Committee are of opinion that the above defects can without difficulty be all remedied, and they argue that, if this gate, working under these disadvantages, satisfies all the conditions required, other gates, from which these errors have been eliminated, will be necessarily more perfect in their action.

7. The Committee then proceeded to test the gate, first, as regards its automatic action. Water was admitted to the reservoir, until it reached the sill of the inlet to the counter-weight chambers. The action was then precisely that described in the attached note. It was also noted, by means of the gauge erected for the purpose, that the gate began to open, when the counter-weight was submerged to a depth of 6 feet 9 inches from the bottom, showing that there was still a margin of power available, as the total height of counter-weight is 7½ feet. The gate was worked repeatedly under varying discharges, and the test was as thorough as the Committee could wish. Secondly, the gate was tested for water-tightness. The set screws, provided to adjust the position of the gate with respect to the frame, were released, and the gate allowed to come into actual contact with the frame. In this position with a full head and with water only 7 feet above the lower edge, it was absolutely water-tight. The water was lowered to within 2 feet of the lower edge; and, as the pressure decreased, a slight separation of the gate from the frame occurred, resulting in leakage to the extent of about ¼ cubic foot per second as a maximum. The set screws were then lowered, so as to bring the gate to its working conditions, *i.e.*, to prevent any contact of the gate with the frame, and the leakage, in the position under heads from 7 feet to 2 feet, varied from ¼ to ½ cubic foot per second.

8. The Committee are unanimously of opinion that the automatic action of the gate, both as to opening and shutting, is practically perfect. They are further of opinion that it is superior to every form of automatic gate they are acquainted with, for storing water in reservoirs to the depth of maximum flood level, or in other positions under similar conditions, because, it is simple in design, completely under control, and so sensitive and certain in its action that the smallest loss of storage water is practically impossible.

9. As regards the leakage observed in the experimental gate, the Committee consider it of no consequence whatever, in the case of the Bhátghar and Gokák weirs. But supposing that, in future gates of this design, it were impossible to reduce the amount of leakage, they would still unhesitatingly recommend this form of automatic gate being adopted in both the works above referred to, and they think it difficult to over-estimate the value and importance of the invention for similar purposes.

10. The Committee think it right to place on record, for the information of Government, that the inventor, Mr. Reinold, assures them with the greatest confidence that gates, from which the defects referred to above have been eliminated, can be made to work with the same certainty as regards automatic action, and also be so water-tight that the leakage would be practically *nil*. This perfection, which is not a necessity in the case of the weirs at Bhátghar and Gokák, might prove to be of great value in other cases.

11. The comparative merits of gates and needles for the south waste weir at Bhátghar, and for the weir at Gokák, have to be considered. The conditions at Bhátghar are such that it is of the utmost importance to have easy and rapid control of the discharge over the weir, when the water in the reservoir has risen to the maximum full supply level, and the Com-

mittee think it would be more satisfactory, if this weir were provided with automatic gates, as well as the north weir. As the site, however, does not admit of this, they are unanimously of opinion that gates that can be easily and rapidly worked, such as Mr. Reinold's roller gate, are a necessity, and that needles in any form are most unsuitable.

12. The conditions in the case of the weir at Gokák are different and such that, if the required number of automatic gates to run off the maximum freshet, be provided, needles might for the sake of economy be used, but that if the expense were not prohibitive, it would be better to use gates, because they are more easily worked, and give more complete control over the discharge at all times.

13. The Committee having proceeded to Poona, assembled on the morning of the 4th March, at the Poona Water Works, the site selected for carrying out the experiment with Mr. Whiting's steel needles.

The needles, 10 in number, 8 feet long and about 8 inches wide, weighing each 90 lbs. had been placed across an opening of 7 feet in width, the head of water being 5 feet.

14. The time occupied in removing the needles was 5 minutes, the head gradually reducing to 2 feet. Replacing them took the same time, the head again increasing from 2 feet to 4½ feet. The leakage, when the needles were in position, was about 1 cubic foot per second, and was principally from the sides, owing to defective fitting of the side pieces. This, no doubt, under improved arrangements, can be materially reduced.

15. The teak needles were then placed in position and removed, the time occupied in both processes being practically the same as for the steel needles. The leakage was also about the same. A small opening, 5½ feet in width, was also experimented on, with steel needles, when the head varied from *nil* to 5 feet with very similar results.

16. The Committee are unanimously of opinion that the result of the experiments with the steel needles was very satisfactory, and that, if the weight and width of the needles were reduced, they would be superior to teak needles for canal regulators, in which the head of water does not exceed 6 feet, notwithstanding their estimated cost is double that of teak needles.

17. For head in excess of 6 feet the Committee consider that further trials are necessary, before an opinion can be given, as they had no opportunity of testing the needles under a greater head than 6 feet.

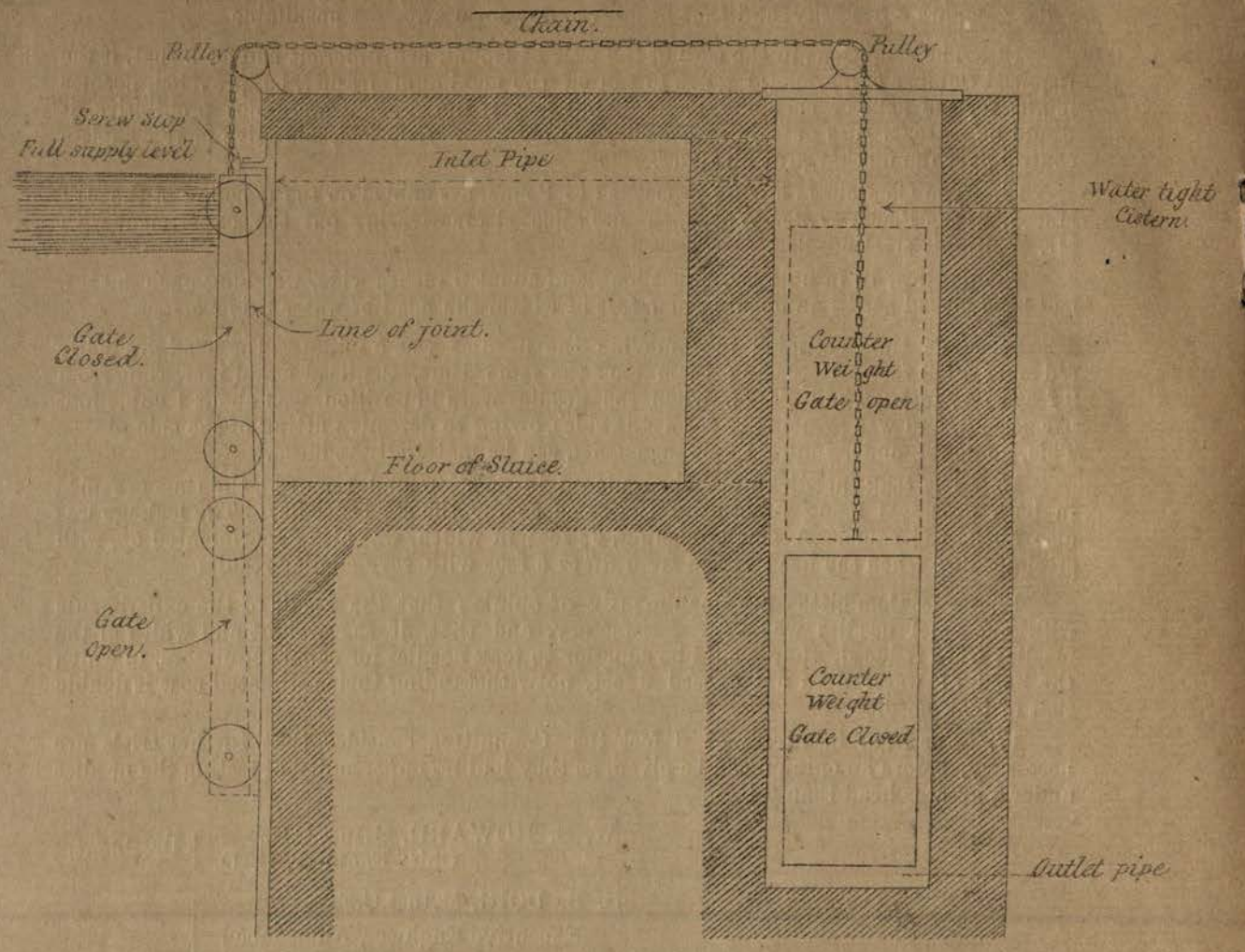
W. S. HOWARD, M.Inst.C.E., Chief Engineer, C. D. } President.

S. B. DOIG, M.Inst.C.E., Executive Engineer, Ahmedabad.

W. H. LEQUESNE, C.E., Executive Engineer, Níra Canal. } Members.

E. F. DAWSON, C.E., Executive Engineer for Irrigation, Dhárwár.

Note on the Experimental Automatic Gate erected at Vir, referred to in para. 2 of the Committee's report.



The above sketch illustrates the general principle of the design. The gate is suspended by means of chains, which, going over pulleys, are attached to a counter-weight, placed in a water-tight chamber, to which water is admitted at level of full supply in the reservoir, and provided at the bottom with an outlet pipe, which always discharges *less* than the maximum discharge from the inlet pipe. When the discharge from the inlet stops, *i.e.*, when the level of the water in the reservoir falls below the sill of the inlet, the outlet pipe, which always remains open, empties the counter-weight chamber. The action is then as follows:—

When the water in the reservoir rises to the level of the inlet pipe, the counter-weight chamber gradually fills and immerses the counter-weight. When the counter-weight has in this manner lost sufficient weight, to release the proportion of the weight of the gate, required to overcome all friction, the gate begins to move downwards, and continues to do so, as long as the water in the chamber rises. When the discharge through the opened sluice lowers the water in the reservoir below inlet level, the water is discharged from the chamber through the outlet pipe, and the counter-weight regains the weight necessary to bring up the gate and close the sluice.

2. The gate weighs 6,328 lbs. The counter-weight is $7\frac{1}{2}' \times 2\frac{3}{4}' \times 5\frac{1}{2}'$, giving a displacement of 113 cubic feet or 7,051 lbs., it is made of wrought-iron $\frac{1}{4}''$ thick, and is quite water-tight. Sand has been added, so as to bring up its net weight to 9,200 lbs.

When the weight hangs free, in air, the power available to draw the gate up is—

9,200—6,328 (weight of the gate)=2,872 lbs.

When the counter-weight is immersed in water, it weighs 9,200—7,051=2,149 lbs. or less than the weight of the gate by 6,328—2,149=4,179 lbs. The power, therefore, to release or open the gate is 4,179 lbs. considerably more than what is available to close it. The weights have been fixed in this manner purposely to have a large balance of power in hand to be quite certain of the opening, and the result, as regards closing, is that the motion is a little slower than it would be, if the counter-weight were made heavier. This, however, can be adjusted hereafter when it has been ascertained by means of a gauge, (which is now being fixed) exactly how much of the counter-weight is immersed, when the gate begins to open, showing the exact power required to overcome all friction.

3. The weights can be adjusted to provide exactly equal power for both opening and closing, by making the counter-weight weigh the weight of the gate *plus* half the weight of its own displacement.

Thus the C. W. $= 6{,}328 + \frac{7051}{2} = 9{,}853{\cdot}5$ lbs., and power to keep the gate closed is 3,525·5 lbs.

The C. W., when immersed, weighs 9,853·5—7,051 = 2,802·5 lbs.

The power then available to release or open the gate is 6,328—2,802·5 = 3,525·5 lbs.

It will be seen that the limit, up to which the actuating power can be brought, is by making the C. W. of such dimensions, that *half* of its displacement equals the weight of the gate.

W. H. LEQUESNE, C.E.,
Executive Engineer, Nira Canal.

Nira Canal Project—Orders on proposals for revisions of design for waste weirs at Bhátghar in connection with the—

No. 51 W. I.—577 of 1891.

Public Works Department.

Bombay Castle,
31st March 1891.

Memorandum from the Chief Engineer, Central Division, No. 1086, dated 11th March 1891.

Forwards copy of a letter from the Executive Engineer, Nira Canal, submitting, for sanction, certain drawings showing his proposals for the revision of the design for the north waste weir at Bhátghar, to adopt Mr. Reinold's patent gate, instead of the falling gate provided in the sanctioned design, drawing for which is also submitted; forwarding also the sanctioned plan of the south waste weir, in which he proposes to substitute non-automatic "roller" gates for the needles; and making remarks. States that the Committee, appointed in Government Resolution No. 7 W. I.—94, dated 17th January 1891, to report on Mr. Reinold's gate and Mr. Whiting's needles have completed their enquiry. Submits a copy of their report for the information of Government. Observes that the Committee recommend the adoption of Mr. Reinold's gate at Bhátghar, automatic in the case of the north waste weir, and non-automatic in the case of the south waste weir. Adds that, if Government approve of these proposals, there would appear to be no objection to the Executive Engineer commencing the necessary masonry work.

RESOLUTION.—In submitting the revised plans and estimates for the Nira Canal project in 1884, it was explained that, in place of the original design for a waste weir, 1,400 feet long, with permanent crest at R. L. 320·20 it was proposed to make the crest at R. L. 317·20 to reduce the length to 807 feet, and to provide by means of a series of 67 "falling gates," of which 30 were to be self-acting, for raising the "full supply level" to the maximum flood level, or 8 feet above the crest of the weir.

2. In submitting the second Revised estimate in 1887, it was further explained that it had, for reasons given, been decided to have two waste weirs, one on the north, and the other on the south flank, the arrangements in other respects remaining as before.

3. The details of the proposed arrangements of gates for closing the weirs to store the water between waste weir crest and highest flood level have never been finally decided, but, according to the latest proposals, it was intended to close the north weir by automatic falling gates, and the south weir by "steel needles."

4. The particular form of "falling gate" proposed was novel, and had been tried only experimentally; and, in the meantime, another pattern of "roller" gate was invented by Mr. E. K. Reinold, which answered so perfectly, when experimented with in the form of a model, that experiment with a full-sized gate was determined upon.

5. Further, the suitability of the arrangement for closing the south weir by "steel needles" was questioned, as it was not clear what its advantages were.

6. These matters were referred to a Committee consisting of—

Mr. W. S. Howard, M.Inst. C.E., Chief Engineer, Central Division,
Mr. S. B. Doig, M.Inst.C.E., Executive Engineer, Ahmedabad,
Mr. W. H. LeQuesne, Executive Engineer, Nira Canal,
Mr. E. F. Dawson, Executive Engineer for Irrigation, Dhárwár.

The Committee have now reported, and appear to be greatly impressed with the result of their experiments with the full-sized gate of the pattern invented by Mr. Reinold. They are unanimously of opinion that its automatic action, both in opening and closing, is practically perfect: that it is superior to every form of automatic gate they are acquainted with for storing water in reservoirs to the depth of maximum flood level, or in other positions under similar conditions, because it is simple in design, completely under control, and so sensitive and certain in its action that the smallest loss of storage water is practically im-

possible: and they unhesitatingly recommend its adoption in the case of both the Bhátghar and Gokák weirs: but in the case of the Bhátghar south weir, as the site does not admit of the application of the automatic principle, they recommend roller gates non-automatic in preference to needles.

7. In the present papers, sanction is requested to proceed with certain portions of the masonry work on both waste weirs at Bhátghar, on the assumption that the foregoing recommendations are accepted.

8. The Chief Engineer, Central Division, reports that there appears to be no objection to this, and it may accordingly be approved. The outlay has been provided for in the revised estimate for the dam, &c., dealt with separately under Government Resolution No. 49 W. I.—570, dated 31st March 1891.

9. The proceedings may be reported for the information of the Government of India.

No. D.—572 of 1891.

PUBLIC WORKS DEPARTMENT.

Chief Engineer's Office, S. D.,
Camp Supa, 8th April 1891.

MEMORANDUM.

In returning the accompaniments to Government Memorandum No. 198 I. of the 1st April 1891, proceedings of a Committee on Mr. Reinold's sluice gate, and Mr. Whiting's steel needles, and Government Resolution No. 51 W.I.—577 of 31st March 1891, dealing with the proposals of the Committee, the Chief Engineer, Southern Division, has the honor, as invited, to offer remarks as under:—

2. As regards the "gates" the conclusion of the Committee is what the Chief Engineer anticipated it would be, but he is still of opinion that it would only be prudent to wait until the floods of one full monsoon had passed over the experimental gate, before deciding finally regarding its merits.

3. As to the "needles" it is to be noted that the Committee leave the question open in so much as they say that for heads in excess of 6 feet, further trials are necessary before an opinion can be given, as they had no opportunity of testing the needles under a greater head than 6 feet; further, an experiment for a width of 7 feet in a store-yard can be of no practical value, when there is a question of the application of the invention to such a work as the Gokák weir, where for no less than 2,208 running feet of weir crest would needles be required, and where the head is 9 feet; though the Committee thus do not professedly give a verdict about "needles," they reject them for use in the south waste weir at Bhátghar, and consider that, "if the expense were not prohibitive, it would be better to use gates" rather than needles at Gokák; this amounts, if not to condemnation of the "needles," to their relegation to a position much below that of the "gates"; with this implied verdict the Chief Engineer concurs, and he is of opinion that, if ever the storage level at Gokák is required to be raised to 34 feet, the full height contemplated by the complete project (25 feet being the height of crest of weir now approaching completion), it would be better to go to the expense of "gates" (*non*-automatic) than to use "needles"; these last will, no doubt, answer very well for canal regulators, but not, the undersigned is of opinion, for storage for such a length and head as is required at Gokák: the undoubted danger, too, accompanying the device of storing water in the dry season by temporary obstructions that *must* be taken down before the commencement of the rainy season, will be much less, if, "gates," instead of "needles," are used.

C. A. GODFELLOW, Major-General, R. E.,
Chief Engineer, Southern Division

APPENDIX No. VIII.

Final Revised Recapitulation of Nira Canal Project.

Sub-head.		Present Revised.	Remarks.
		Rs.	
IRRIGATION MAJOR WORKS.			
PROTECTIVE WORKS.			
CAPITAL ACCOUNT.			
NIRA CANAL.			
I. Works.			
1. *Head Works.*			
A. Preliminary Expenses		12,512	
B. Land		2,37,500	
C. Works		18,53,410	
K. Buildings		13,282	
J. Mills...		8,000	
M. Plantations		7,084	
P. Maintenance		3,617	
Total 1—Head Works ...		21,35,405	
2.—Main Canal and Branches.			
A. Preliminary Expenses		22,241	
B. Land		31,210	
D. Regulators		26,556	
F. River and Hill Torrent Works—			
Aqueducts	2,40,373		
Culverts	2,01,416	5,18,942	
Natural or Pitched Escapes ...	5,678		
Super-passage	71,475		
G. Bridges		54,466	
J. Mills		.....	
K. Buildings		33,803	
L. Earthworks		12,05,447	
M. Plantation		10,603	
O. Miscellaneous		1,584	
P. Maintenance		12,670	
Total 2—Main Canal and Branches ...		19,17,522	
3.—Distributaries.			
A. Preliminary Expenses		4,317	
B. Land		12,579	
C. Works		1,23,530	
L. Earthworks		1,44,101	
O. Miscellaneous		16,701	
P. Maintenance		500	
Total 3—Distributaries ...		3,01,728	
Total I. Works ...		43,54,655	

CULTIVATED AND UNCULTIVATED AREA.

Táluka.	Number and area of villages.						Population.		Land Revenue.	Area for which agricultural statistics are available.						
	Government.		Alienated.		Total.								Area cultivated.			
													Cropped Net.			
	Number.	Area in square miles.	Number.	Area in square miles.	Number.	Area in square miles.	Total, 1881.	Density per square mile.		Villages.	Area in acres.	Percentage of column 12 on the gross area.	Irrigated.	Not irrigated.	Fallows.	Total.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
										As-sumed.						
Indápur ...	49	305	4	12	53	317	27,040	85	60,414	53	188,373	...	4,364	163,065	8,881	176,310
Purandhar ...	2	6	...	...	2	6	984	163	1,281	2	1,479	...	51	1,013	152	1,216
Bhimthadi ...	27	142	...	...	27	142	15,129	107	32,400	27	84,595	...	3,464	70,554	6,277	80,295
Total ...	78	453	4	12	82	465	43,153	...	94,095	82	274,447	...	7,879	234,632	15,310	257,821

CROPS—*continued.*

Táluka.	Orchard and Garden Produce.				Drugs and Narcotics.			Condiments and spices.	Sugar-cane.	Oil-seeds.						Dyes.	Fibres.		
	Vegetables.	Green Fodder.	Fruit trees.	Total.	Tobacco.	Others.	Total.			Sesam.	Safflower-seed.	Niger-seed.	Ground-nut.	Others.	Total.		Cotton.	Others.	Total.
1	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
Indápur ...	147	5	18	170	132	...	132	462	152	324	17,289	53	139	273	18,078	...	6,910	1,495	8,405
Purandhar ...	6	1	2	9	...	...	...	6	3	...	25	10	2	...	37	...	...	1	1
Bhimthadi ...	120	14	19	153	70	...	70	204	131	128	5,955	6	64	75	6,228	..	7	296	303
Total ...	273	20	39	332	202	...	202	672	286	452	23,269	69	205	348	24,343	...	6,917	1,792	8,709

Táluka.	Water-supply.									Holdings.									
	Wells in use.			Tanks.			Other sources.			Number of holdings.						Total Area.	Average.		
	For irrigation.	For drinking.	For cattle and washing.	For irrigation.	For drinking.	For cattle and washing.	For irrigation.	For drinking.	For cattle and washing.	Under and up to 5 acres.	Over and up to 25 acres.	25 to 100 acres.	100 to 500 acres.	Over 500 acres.	Total number.		Area of Holding.	Assessment per holding.	Assessment per acre.
1	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
																		Rs. a. p.	Rs. a. p.
Indápur ...	735	61	10	7	1	1	3	119	14	109	603	1,823	276	2	2,813	140,431	49·9	21 4 0	0 6 10
Purandhar ...	24	7	...	...	...	...	2	...	...	13	33	27	2	...	75	2,160	28·4	16 0 0	0 9 0
Bhimthadi ...	408	57	23	1	1	2	4	10	9	29	339	741	135	1	1,245	62,846	50·5	25 5 10	0 8 1
Total ...	1,167	125	33	8	2	3	9	129	23	151	975	2,591	413	3	4,133	205,437	...	...	..

No. IX.

Statistical Tables.

Area uncultivated.				UNDER CANAL.		CROPS.												
						Cereals.							Pulses.					
Available for cultivation.	Not available for cultivation. Forest.	Not available for cultivation. Others.	Not available for cultivation. Total.	Irrigable.	Not irrigable.	Jowári.	Bájri.	Paddi.	Wheat.	Coarse grain.	Others.	Total.	Tur.	Gram.	Mug and Urid.	Math and Kulthi.	Others.	Total.
18	19	20	21	21A	21B	22	23	24	25	26	27	28	29	30	31	32	33	34
...	12,063			154,133	21,843	89,807	31,124	166	2,817	107	700	124,721	2,794	4,149	657	9,144	33	16,777
...	263			1,247	233	355	501	13	45	36	9	959	9	35	11	52	3	110
...	4,300			72,290	11,389	44,243	19,725	122	1,186	78	223	65.577	509	1,182	93	1,710	8	3,502
...	16,626			227,670	33,465	134,405	51,350	301	4,048	221	932	191,257	3,312	5,366	761	10,906	44	20,389

			AGRICULTURAL STOCK.																	
			Cattle.													Ploughs.		Carts.		
Grass area cropped.	Deduct area twice cropped.	Remainder net area cropped.	For Plough.		For Breeding.		For other purposes.		Milch cattle.		Young Stock.			Horses and ponies.	Sheep.	Goats.	Small.	Large (i.e. of over 2 cattle).	For passengers.	For produce and goods.	Cropped land per pair of plough cattle.
			Oxen.	He-buffaloes.	Bulls.	Bull buffaloes.	Oxen.	He buffaloes.	Cows.	She buffaloes.	Calves.	Buffaloe calves.	Total.								
54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
168,897	1,468	167,429	14,457	583	10	3	208	83	8,106	1,717	5,845	1,108	32,120	803	30,584	6,521	69	1,574	39	946	22·4
1,125	61	1,064	155	2	...	...	3	...	80	21	37	11	309	9	124	43	7	17	1	8	14
76,166	2,150	74,016	7,073	70	18	3	231	37	3,981	543	1,851	299	14,106	499	13,648	2,862	81	626	22	501	21·4
246,188	3,679	242,509	21,685	655	28	6	442	120	12,167	2,281	7,733	1,418	46,535	1,311	44,356	9,426	157	2,217	62	1,455	...

Incidence of Assessment.					Prices, February 1888.								
Fully assessed occupied area.			Fully assessed area including alienated land in Government villages.		Price in Lbs. per rupee of				Price in Lbs. per rupee of		Wages per diem per man.		
Area.	Assessment.	Incidence per acre.	Population.	Incidence per head of population including alienation	Jowári.	Bájri.	Rice in husk.	Tur (dal).	Kadbi.	Dry grass.	Skilled labour.	Ordinary labour.	Field labour.
95	96	97	98	99	100	101	102	103	104	105	106	107	108
Acres.	Rs.	Rs. a. p.	Rs.	Rs. a. p.							Rs. a. p.	Rs. a. p.	Rs. a. p.
132,383	58,147	0 7 0	23,079	2 10 10	51	37	27	33	162	101	0 8 0	0 3 0	0 4 0
1,839	1,149	0 10 0	695	1 14 6	42	37	...	30	...	125	0 10 0	0 4 0	0 4 0
56,645	30,747	0 8 0	13,615	2 8 2	48	36	41	26	168	...	0 10 0	0 4 0	0 3 0
190,867	90,043	...	37,389	.....	141	110	68	89	330	226	...	...	...

Stations.		January to April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.	Remarks.
Vir bungalow	Maximum 1889 ...	...	2·89	1·98	3·01	1·38	15·47	6·54	...	...	31·27	
	Minimum 1885 ...	0·54	1·72	0·61	3·34	1·23	6·38	2·22	0·61	0·86	17·51	
	Average	0·95	1·58	2·61	3·44	1·24	5·88	3·80	1·25	1·23	21·98	
Pimpra	Maximum 1889 ...	...	6·68	1·81	1·80	1·43	13·53	9·14	...	...	34·39	
	Minimum 1885 ...	0·59	0·71	0·23	3·06	1·12	7·86	4·31	0·63	0·23	18·74	
	Average	1·26	2·24	2·70	2·53	1·24	6·76	5·24	1·51	1·18	24·66	
Vadgaon	Maximum 1887 ...	0·43	1·95	4·00	1·62	0·55	10·62	6·57	6·56	0·05	32·35	
	Minimum 1888 ...	2·08	0·40	1·75	1·39	0·76	4·41	1·46	1·93	...	14·18	
	Average	0·74	1·94	2·19	1·49	1·07	7·48	5·65	2·59	1·32	24·47	
Pandára	Maximum 1889 ...	0·04	3·00	0·53	2·03	0·12	15·93	9·60	...	...	31·25	
	Minimum 1888 ...	1·71	0·61	1·31	0·79	0·24	4·54	1·09	2·58	0·12	12·99	
	Average	0·81	1·34	2·06	1·47	1·22	9·00	4·58	1·73	1·02	23·23	
Bárámati	Maximum 1886 ...	...	2·98	1·71	1·75	5·21	1·81	10·83	0·94	3·55	28·78	
	Minimum 1885 ...	0·39	0·91	0·24	1·63	0·52	10·98	3·37	...	0·45	18·49	
	Average	0·71	1·34	2·67	1·59	1·76	7·49	3·95	1·66	1·30	22·47	
Sansar	Maximum 1889 ...	...	1·38	0·92	3·24	0·34	15·83	7·25	...	...	28·96	
	Minimum 1888 ...	1·38	0·27	5·32	0·54	0·71	4·28	1·78	6·49	0·15	20·92	
	Average	0·61	1·43	2·39	1·49	1·64	8·97	4·02	2·60	0·88	24·03	
Haturneh	Maximum 1889 ...	0·10	0·13	0·96	3·41	...	13·07	6·09	...	...	23·76	
	Minimum 1888 ...	1·48	0·64	3·89	1·00	0·95	4·83	1·58	4·66	0·10	19·13	
	Average	1·09*	0·93	2·94	1·99	1·37	7·21	2·72	2·82	0·69	21·76	* Average for 3 years for April, rest for 4 years, 1887, 1888, 1889, 1890.
Nimbgaon	Maximum 1889 ...	1·13	1·04	2·82	2·70	0·17	12·98	6·60	...	...	27·44	
	Minimum 1890 ..	0·69	1·52	2·87	0·65	1·32	4·52	1·31	3·20	1·36	17·44	
	Average	1·11	0·88	2·64	1·60	0·72	7·97	3·46	2·93	0·46	21·77	For 3 years only, 1888, 1889 and1890.
Indápur	Maximum 1889 ...	0·14	0·26	2·38	5·62	0·37	17·15	8.05	...	...	33·97	
	Minimum 1888 ...	1·68	0·09	3·99	1·06	0·80	3·18	1·98	5·40	0·34	18·52	
	Average	0·61	1·26	3·45	2·82	2·31	8·50	5·58	1·68	1·22	27·43	

Extract paras. 2—7 of letter No. 2447, dated 30th October 1891 from the Executive Engineer, Nira Canal.

"2. The only accurate figures are those in columns 2, 4 and 6, 3, 5 and 7, 12, 17, 20, 21 and 21A and 21B. } For villages—area in square miles, area in acres.

3. For the other figures I have made use of the statistical atlas prepared in 1888 by the Director of Land Records and Agriculture. The square mileage shown in column 7 represents the absolute gross area between the canal and the river; the gross acreage shown in column 12 represents the whole area to which water can be supplied by flow and in column 17 the cultivable portion of this is given, the uncultivable part being put in column 20. I have put the same numbers to the columns as those in the statistical atlas for facility of reference. Two fresh columns 21A, 21B have been added for information; they are not used in any of the calculations.

4. The calculations have been made on the following proportions :—

	Indápur.	Purandhar.	Bhimthadi.
	Sqr. miles.	Sqr. miles.	Sqr. miles.
Total area of táluka ...	564	464	1,036
Area under Nira Canal ...	317	6	142
Proportion of whole area ...	0·562	0·013	0·137

for obtaining the Population, Land Revenue, Water-supply, Incidence of Assessment, and Holdings.

But for the Agricultural Statistics, *viz* :—

Crops.
Agricultural stock.

I have taken the proportion of cultivable area as shown in column 17 as follows :—

Column 17.	Indápur.	Purandhar.	Bhimthadi.
	Acres.	Acres.	Acres.
Total for táluka ...	258,411	221,202	505,720
Area under Nira Canal ...	176,310	1,216	80,295
Proportion of full area ...	0·682	0·0055	0·159

I have adjusted small differences due to fractions in the column 16 for fallow land.

5. The price of grain and the wages are copied from the atlas. The rainfall is given for each of the guaging stations along the canal for the years from 1885 to 1890 as complete records are obtainable for most of the stations for these years. The figures for Haturne and Nimbgaon are for *1887-1890* and *1888-1890* respectively.

6. It will be observed from the above that the information given is far from accurate, and some columns, where the information was not available, I have left blank. But I have not been able to get any figures from the other departments to which I referred in the matter, and so these proportional statistics are submitted as the only available information. If accepted as sufficiently accurate, they record the state of this part of the district before the canal was brought into operation. A future statement drawn out on the same lines on the next issue of the statistical atlas will show to a certain extent the difference produced by the operation of the canal. This will not be noticeable in Purandhar, but the Bhimthadi and Indápur Tálukas should show a decided improvement in agricultural results.

7. The absolute difference will not be obtainable, as it will be included in the whole táluka figures and will undergo the same proportional reduction as the original figures, see paragraph 4."

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on 31 October, 2019